THE EFFECTS OF COMPETITION ON DEFENSE CONTRACTOR PRICING BEHAVIOR

by

Melinda Ann Maxwell

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APPROVED:

David I. Meiselman, Chairman

Robert J. Mackay

Alan N. Freiden

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Blacksburg, Virginia

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Committee Chairman: David I. Meiselman
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(ABSTRACT)

This study investigates the effects of competition on the pricing behavior of defense contractors. Prior research in this area has indicated a potential for significant price reductions associated with competition.

Pricing data for five dual source subsystems of the AIM-9M Sidewinder missile were examined. Key findings of the study include:

- The introduction of a second source led to increased price reductions by the first source;
- The first source exhibited a greater price sensitivity to lot quantity changes than the second source;
- The second source was immediately price competitive with the first source; and,
- Each subsystem showed evidence of gaming.

ACKNOWLEDGEMENTS

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I would like to express my sincere appreciation to for his help and guidance through the course of this study. In addition, special thanks go to and the staff of the AIM-9M program office for providing the data used in the study. Finally, I would like to thank my dad for his encouragement and support over the past five years.

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CHAPTER 1

INTRODUCTION

Competitive procurement of defense goods and services is an objective of Congress and The Department of Defense (DoD). The Competition in Contracting Act of 1984 legally mandates the use of competition throughout the weapon acquisition cycle. Numerous benefits have been attributed to competition, ranging from increases in weapon quality to an enhanced industrial base. The most often-cited benefit has been a reduction in unit costs, leading to overall program savings.

The purpose of this study is to examine the effects of competition on defense contractor pricing behavior. This will be accomplished through analysis of contractor pricing data from dual source subsystems of the AIM-9M Sidewinder missile. To this end, Chapter 2 presents the analytic approach used by DoD to estimate weapon acquisition costs, as well as the results of recent research in this area. A discussion of production competition and its effects on contractor pricing is presented in Chapter 3. Chapters 2 and 3 also present the methodologies which will be employed in analyzing the AIM-9M Sidewinder data. Chapter 4 describes the DoD competitive procurement process. The AIM-9M Sidewinder missile program is discussed in Chapter 5. Chapter 6 presents the empirical results of this study. Conclusions are given in Chapter 7.

CHAPTER 2

ANALYTIC FRAMEWORK

The Department of Defense (DoD) has traditionally used learning curves to estimate weapon system procurement costs. More recently, the effect of production rate variations also has been taken into consideration in the estimation of procurement costs. This chapter introduces the learning curve and production rate concepts. In addition, several learning curve/production rate models are discussed.

2.1 LEARNING CURVES

The learning curve reflects a reduction in minimum required labor hours as production quantity increases. The convention most widely used is percent reduction in required labor hours based upon a doubling of the cumulative production quantity. This reduction is attributed to worker "learning" or experience. A typical learning curve, also referred to as an improvement curve, experience curve, or progress curve, is shown in Figure 2.1-1.

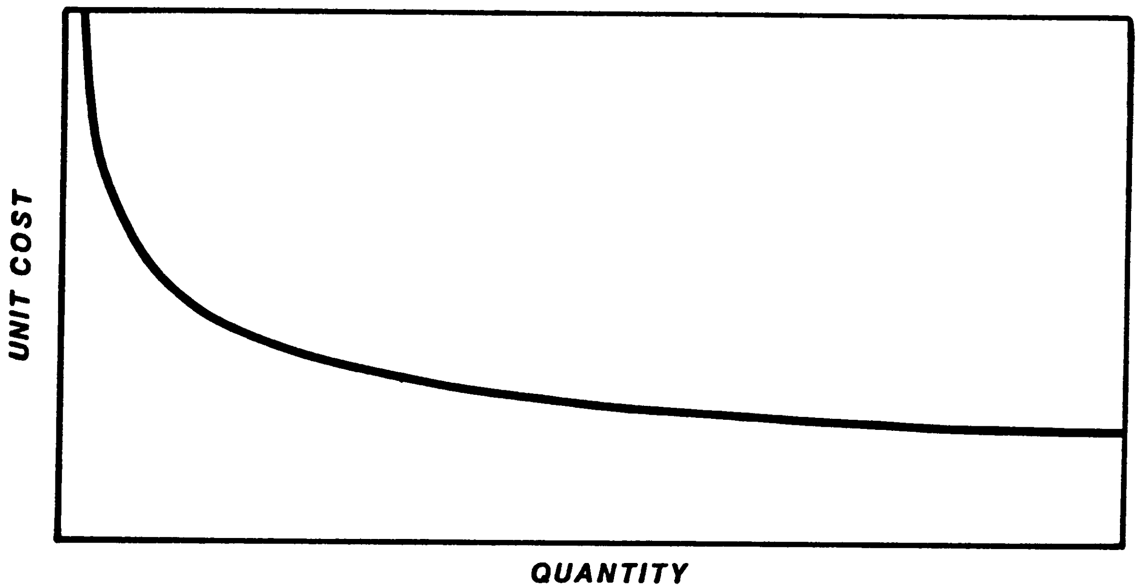

Figure 2.1-1 Typical Learning Curve

It is important to note that the learning curve is phenomenological in nature. The concept was developed based upon historical experience and empirical cost/quantity data. The initial work on learning curves was done by Col. Leslie McDill in 1925 at McCook field in Dayton.[1] Dr. T.P. Wright suggested a more precise formulation of the learning curve in 1936 based upon airframe manufacturing experience.[2] Unlike traditional microeconomics, learning curves have no detailed theoretical underpinnings. They are, rather, an

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[1]Kankey, Roland D., "Learning Curves: An Overview," Estimator, p. 18, 1983.

[2]Wright, T.P., "Factors Affecting the Cost of Airplanes," Journal of Aeronautical Science, 3, pp. 122-128, 1936.

aggregate representation of the results of many factors. Some of these factors may be:

- Increase in supervisory and employee familiarity with production methods
- Improvements in the production methods employed
- Improvements in fixtures, tooling, and machinery
- Development of more efficient handling and materials movement systems
- Overt management action such as product redesign
- Material substitution
- Shared production experience with similar production activities
- Reductions in scrap and waste
- Economies of scale.

In recent years, the basic learning curve format has been expanded to incorporate other recurring costs associated with production.[3] It has been observed that the recurring costs of production follow a pattern similar to that of labor hours; that is, an increase in cumulative quantity leads to a reduction in unit cost. Two mathematical formulations of the cost reducing behavior of learning curves have been developed. The cumulative average formulation assumes the cumulative average cost of

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[3] Perspective on Experience, Boston Consulting Group, 1968.

production decreases by a constant percentage as cumulative quantity of units produced doubles. This can be mathematically expressed as given in equation 2.1-1.

$$C_N = AN^B \qquad (2.1\text{-}1)$$

where:

C_N = the cumulative average cost at the N^{th} unit

A = a constant defined as the first unit cost

N = the number of completed units

B = the exponent of cost reduction defined as the ln (learning rate)/ln (2).

The unit learning curve formulation assumes that the unit cost required to complete a specific unit declines by a constant percentage each time the cumulative quantity completed doubles. This can be mathematically expressed as given in equation 2.1-2.

$$Y_n = AN^B \qquad (2.1\text{-}2)$$

where:

Y_n = the unit cost of the N^{th} unit

A = a constant defined as the first unit cost

N = the number of completed units

B = the exponent of cost reduction defined as the ln (learning rate)/ln (2).

Although similar in notation, the two formulations present different cost relationships. The cumulative average formulation presents an average cost up to a given unit that is weighted by the cost of all prior units. The unit formulation presents a unit cost that is not influenced by the cost of prior units. This study will utilize the unit formulation because it more readily reveals the dynamic aspects of the impact of competition on cost behavior. By its very nature, a cumulative average curve tends to mask changing cost behavior due to competition because the cumulative average cost of the competitive units is influenced by the costs of the prior non-competitive units.

Learning or cost improvement curves are used within DoD to estimate weapon system procurement costs. Future weapon system costs are forecasted based upon the estimated cost improvement curves from prior procurements.

These cost improvement curves are estimated within the DoD by employing logarithmic transformation of the cost and quantity data and by performing ordinary least squares (OLS) estimation. This approach has several advantages including analytic convenience and the generation of meaningful test statistics for individual variables. This estimation approach suffers from two limitations:

- Bias associated with selection of lot midpoints
- Specification bias associated with the omission of variables.

These limitations present difficulties in interpreting historical results and thus, in forecasting future costs.

To estimate unit cost improvement curve parameters, one must calculate average unit cost per lot and lot midpoints. Lot midpoints are defined as the unit whose cost equals the average unit cost for the lot, thus the true lot midpoints are a function of the cost improvement rate, as demonstrated by The Rand Corporation.[4] The estimation of the parameters is accomplished using log-linear transformations of the variables and the OLS estimation technique. In addition, Goldberger has shown that the log transformation leads to biased estimates of the first unit cost.[5]

Several techniques have been suggested to remove the bias due to midpoint estimation. One such method involves estimating the learning curve slope, recalculating lot mid-

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[4]"Military Equipment Cost Analysis," The Rand Corporation, Santa Monica, CA., 1971.

[5]Goldberger, A.S., "Best Linear Unbiased Prediction in the Generalized Linear Regression Mode," <u>Journal of the American Statistical Association</u>, 157, 1962.

points, and continuing on an iterative process until convergence. Womer has estimated the exponential form of the cost improvement curve through nonlinear regression techniques.[6]

The other limitation of the cost improvement curve is the implicit assumption that all cost reductions are strictly related to cumulative quantity produced. The learning curve formulation includes no other explanatory variables. Such a formulation ignores the relationship between unit cost and production rate.

The intuitive and empirical results of incorporating production rate into the unit cost equation have been reported by The Analytic Sciences Corporation (TASC)[7] and Bemis.[8] The mathematical implications have been discussed by Crouch[9] and Womer[10]. Estimation of learning curve

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[6]Womer, N.K., and Patterson, J.W., "Estimation and Testing of Learning Curves," Journal of Business and Economic Statistics, Volume 1, Number 4, October 1983.

[7]Cox, L. and Gansler, J., "Evaluating the Impact of Quantity, Rate, and Competition," CONCEPTS, Volume 4, Number 4, Autumn 1981.

[8]Bemis, J.C., "A Model for Examining the Cost Implications of Production Rate, CONCEPTS, Volume 4, Number 2, Spring 1981.

[9]Crouch, R., "Avoiding Bias in Progress Functions," Defense Management Journal, Third Quarter 1980.

[10]Womer, N.K., "Learning Curves, Production Rate and Program Costs," Management Science, 24, 1979.

parameters that do not include consideration of production rate suffer from a specification bias. This bias will tend to overstate or understate the learning phenomenon, depending on whether production rates increased or decreased during the period for which the learning curve is being estimated.

2.2 PRODUCTION RATE

The use of economic production rates is a stated objective of DoD. This objective has been emphasized in the Defense Acquisition Improvement program and subsequent initiatives undertaken by former Deputy Secretary of Defense Thayer.

Consideration of production rate in economic theory and empirical research has concentrated on the unit cost effects of expanding plant or firm size. Economic theory suggests that as production rate is increased, unit costs decline to some minimum point. This declining cost is due to capital amortization, specialization of labor, absorption of fixed costs, and increased administrative efficiencies.

Theory also suggests that unit costs increase if production rate is increased beyond the minimum point.[11] In the short run, these increases are due to lower productivity of newly hired workers, additional labor costs associated with overtime, overburdened capital equipment, and increasing management complexity.

In the long run, capital is considered variable and a given plant site can be augmented by an expanded capital stock. Unit cost increases in the long run are due to diminishing management efficiency, rather than technical limitations such as plant capacity. Thus, in the short run and the long run, the relationship between unit cost and production rate is presented as a U-shaped curve.

The U-shape of the long run curve has been developed further to reflect greater flexibility in the manufacturing process. This leads to a bathtub shape curve as shown in Figure 2.2-1. The curve presents a declining unit cost region, a flat mid-region where cost is insensitive to changes in production volume, and an increasing cost region.[12] The increasing cost region reflects management inefficiencies.

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[11] Mansfield, E., Microeconomics, Theory and Applications, W.W. Norton and Company, Inc., New York, N.Y., 1970.

[12] Scherer, F.M., Industrial Market Structure and Economic Performance, Second Edition, Houghton Mifflin Company, Boston, Mass., 1980.

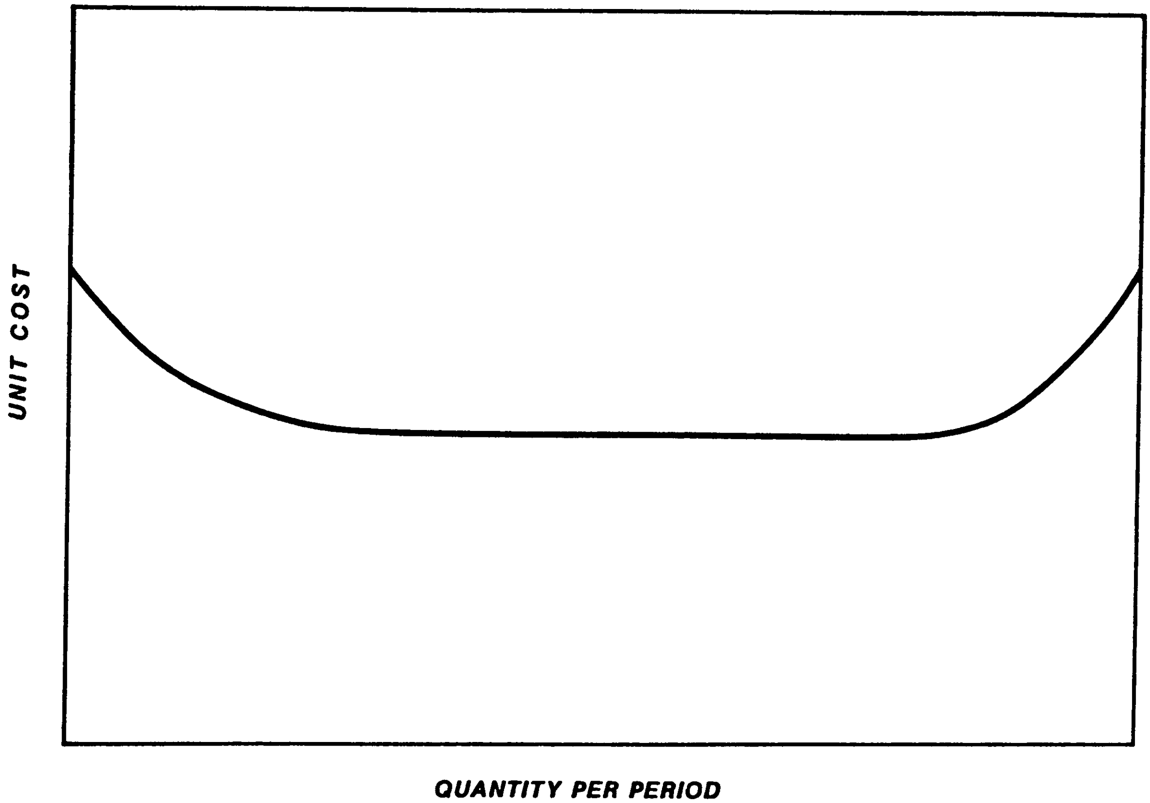

Figure 2.2-1 Long Run Unit Cost Curve

2.3 LEARNING CURVE/PRODUCTION RATE MODELS

Numerous studies on the effect of production rate on weapon system procurement cost have been undertaken. This section presents the results of studies in this area.

A detailed statistical study of the relationship between unit cost and production rate was undertaken by Rand in 1974.[13] This effort employed linear regression techniques to investigate the effect of production rate on manufacturing labor, materials, tooling, engineering, and labor rate. The authors concluded the influence of production rate could not be predicted with confidence, since the statistical analysis presented diverse results, requiring program specific analysis.

In 1976, Smith also attempted to incorporate production rate considerations into the learning curve concept.[14] Smith's formulation expressed labor hours as a function of cumulative quantity and production rate per period. The production rate effect was expressed similarly to the learning curve. Smith reported a significant improvement in estimating prior learning curves as demonstrated by a reduction in mean squared error.

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[13]Large, Joseph P., et. al., "Production Rate and Production Cost," The Rand Corporation, R-1609-PA&E, December 1974.

[14]Smith, Larry Lacross, <u>An Investigation of Changes in Direct Labor Requirements Resulting from Changes in Airframe Produciton Rate</u>, Ph.D. Dissertation, University of Oregon, 1976.

This concept was expanded by Bemis to include total recurring unit cost.[15] Bemis expressed total recurring unit cost as a function of cumulative quantity and production rate per period. The model parameters were estimated by estimating lot midpoints, taking logarithmic transformations, and performing multivariate linear regression. This technique, although convenient, may suffer from midpoint bias as discussed in Section 2.1. In addition, the Bemis model implies that unit costs decrease indefinitely. The Bemis formulation presents several analytic advantages. First, unlike the quadratic formulation of economic theory, the formulation can be estimated with relative ease. Second, the data necessary to estimate the model is readily available to researchers and program managers.

Other approaches to production rate have been suggested. Typically, these formulations present substantial data requirements in order to estimate the model parameters. The formulation suggested by the Army Procurement Research Office (APRO) is similar to a learning curve approach, except that it requires segregation of fixed

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[15]Bemis, J.C., "A Model for Examining the Cost Implications of Production Rate," CONCEPTS, Volume 4, Number 2, Spring 1981.

costs.[16] The APRO formulation identifies total production costs as a function of recurring and fixed costs. This is an intuitively appealing approach; however, its general application is limited by data availability.

A more detailed approach has been suggested by Womer.[17] Womer's formulation expresses airframe labor hour costs as a function of worker learning through experience, training, and speed and length of the production line. Womer's model involves a complex formulation estimated using nonlinear least squares. The data requirements associated with Womer's formulation are extensive. Release dates, delivery dates, man-hours per aircraft, and other manufacturing data must be used to apply the model.

TASC presented a production rate formulation that built upon the efforts of Smith and Bemis.[18] It differed from prior formulations in two respects:

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[16]Smith, Charles A., "Production Rate and Weapons Systems Cost: Research Review, Case Studies and Planning Model," Army Procurement Research Office, APRO-80-05, November 1980.

[17]Womer, N.K., "An Automated Airframe Production Cost Model," Proceedings of the 1983 Federal Acquisition Research Symposium, Williamsburg, VA., December 1983.

[18]Bohn, Michal and Kratz, Louis A., "Analysis of Production Rate Effects on Unit Costs," The Analytic Sciences Corporation, EM-228-WA, January 1984.

- The TASC concept incorporated increasing unit costs due to increased production rates beyond a minimum cost point, assuming a fixed plant
- Parameters for the model were estimated using nonlinear techniques.

The TASC formulation considers unit cost to be a function of production rate and cost improvement. This yields the three-dimensional surface displayed in Figure 2.3-1. Mathematically, it can be expressed as shown in equation 2.3-1.

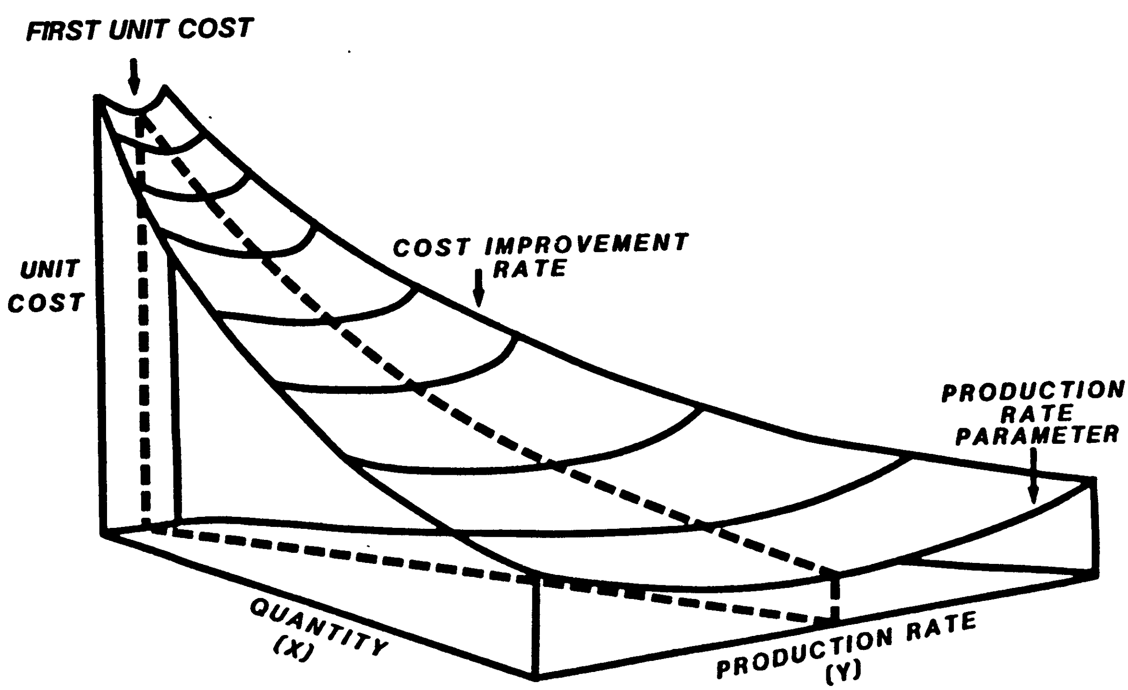

Figure 2.3-1 TASC's Rate Model

$$Z = AX^{B}Y^{C} \qquad (2.3\text{-}1)$$

where:

Z = unit cost of the X^{th} item produced

A = a constant defined as the first unit cost

X = cumulative quantity produced

B = coefficient which describes the slope of the quantity/cost curve, defined as the ln (cost improvement rate)/ln (2)

Y = production rate in effect

C = coefficient which describes the slope of the rate/cost curve, defined as the ln (production rate)/ln (2).

First unit cost is a real number that represents the intercept value of the cost improvement curve. It is not an identifiable cost but an analytically derived starting point. Its expected regression sign is positive.

The cost improvement rate is a real number used to define the slope of the quantity/cost curve. It differs from the traditional learning curve in that it incorporates all recurring costs rather than just labor costs. Its expected regression sign is negative. The parameter B, from which the cost improvement rate is derived, must be negative in order to yield a cost improvement rate which is less than one.

The production rate parameter is a real number used to define the slope of the rate/cost curve. The formulation assumes the existence of an optimum (most cost efficient) production rate, denoted R_o. It is assumed that the production rate is symmetric about R_o. Production costs are minimized when the production rate is R_o, and increase as one deviates from R_o in either direction. This formulation imposes the restriction that the maximum allowable production rate is $(2 \times R_o) - 1$. Similar to the cost improvement rate, the production rate parameter presents the percent change in unit cost due to changes in the production rate or quantity per period. A "95 percent" production rate parameter represents a five percent change in unit cost as production rate doubles from N units per period to 2N units per period. Its expected regression sign is negative. The parameter C, from which the production rate parameter is derived, must be negative in order to yield a production rate parameter which is less than one.

The TASC Rate model is estimated using a weighted least-squares estimation of the nonlinear function based on a generalization of Newton's method for finding the roots of an equation.[19] It is similar to the Gauss-Newton method of minimizing the sum of squared errors in that it enables estimation of an inherently nonlinear equation without the need to employ logarithmic transformations. This avoids the

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[19] Handbook of Applied Mathematics, edited by Carl Pearlson, Von Nostrand Reinhold Company, New York, N.Y., 1974.

bias problem identified by Goldberger and discussed earlier. The TASC approach also removes the error associated with lot midpoint estimation by not requiring identification of lot midpoints.

The learning curve/production rate formulation has been generalized from cost to price estimation by analysts within DoD. This generalization is reasonable, in that contractor profit is negotiated as a function of cost for DoD material. The price formulation will be expanded in Chapter 3 to demonstrate contractor pricing behavior on competitive programs.

CHAPTER 3

PRODUCTION COMPETITION

Numerous benefits have been attributed to production competition, ranging from increases in equipment quality to improvements in industrial productivity. The most often-cited benefit has been a reduction in unit prices, leading to overall program savings. This chapter presents the results of recent research regarding the effects of production competition on the behavior of first and second source contractors. In addition, actual pricing data from two ongoing dual source programs are presented.

3.1 SECOND SOURCE PRICE BEHAVIOR

Recent research on the effect of dual sourcing tactical missiles has indicated that second source producers have demonstrated steeper price improvement rates than the initial producer of the same equipment.[20] This behavior is illustrated in Figure 3.1-1. As shown, the steeper price improvement rate enables the second source to exert price pressure on the initial source. Observed price improvement

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[20]Kratz, Louis A., et. al., "Competition During Army Weapon System Acquisition," The Analytic Sciences Corporation, TR-4613-8, 21 June 1985.

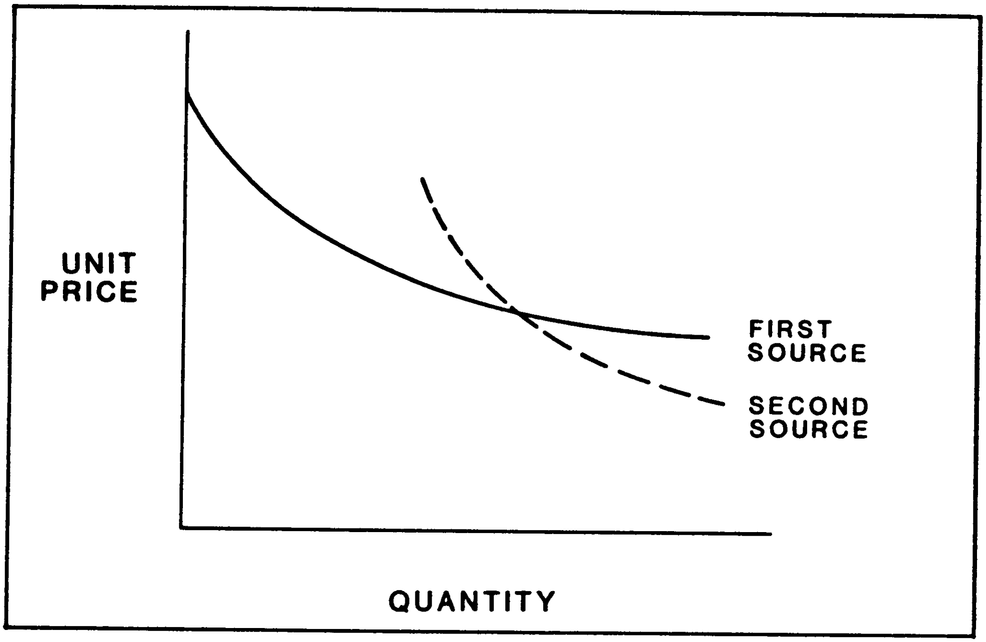

Figure 3.1-1 Second Source Price Behavior (Missile)

TABLE 3.1-1

MISSILE DUAL SOURCE PRICING BEHAVIOR

PROGRAM	PRICE IMPROVEMENT RATE		PERCENT DIFFERENCE
	FIRST SOURCE	SECOND SOURCE	
AIM-7F	0.87	0.84	3
BULLPUP	0.82	0.80	2
TOW	0.98	0.89	9
AIM-9L	0.90	0.83	7
HELLFIRE	0.94	0.92	2
TOMAHAWK	0.79	0.71	8

rates for recent competitive missile programs are shown in Table 3.1-1.

Several reasons have been suggested to explain the consistently steeper second source price improvement curve; however, limited empirical data exist. For example, the second source may avoid many of the problems encountered by the first source in transitioning the system from development to production; thus achieving improved cost performance and correspondingly lower prices. In addition, the second source, realizing the first source has an advantage with regard to cumulative quantity, may price competitively from the onset of production through more efficient make/buy decisions. Furthermore, the steeper curve may result from continuous productivity improvements that are realized due to competitive pressure.

Competitive production has different effects on costs, depending upon equipment technology. For prior electronics programs the second source has been able to reduce costs below that of the original producer immediately. Similar results have been observed for simple subsystems such as on the Patriot missile. For more complex systems such as missiles, missile guidance systems, and ships, the second source undergoes a learning period prior to competitive pricing. These differing effects are presented in Figure 3.1-2.[21]

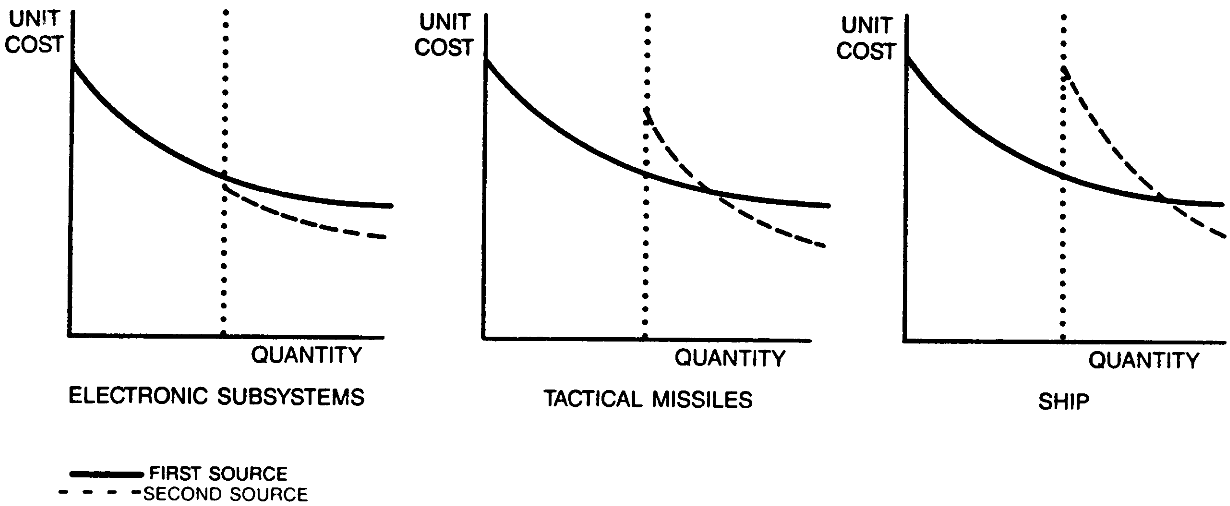

Figure 3.1-2 Second Source Price Behavior

Several explanations have been postulated for the different pricing behavior due to competition across different commodity groups. For example, technology transfusion across the industry could affect pricing. In the dynamic electronics industry, where technical transfusion is rapid, potential second sources have immediate access to new technologies and can be competitive immediately. In industries with slower transfusion rates, second source producers require a longer learning period.

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[21]Kratz, Louis A., et. al., "Competition of Defense Procurements: Evidence, Theory, and Application," The 1982 Federal Acquisition Research Symposium, Washington, D.C., May 1982.

Another determining factor is the complexity of the equipment with regard to internal and external interfaces. Many of the competitive electronics programs involved limited external interface requirements, thus providing the second source producers with internal design flexibility to implement cost-reducing changes. Similarly, the dual source subsystems involved limited external interfaces with associated internal design flexibility. For the missile programs, more stringent interface and design requirements were employed, thus limiting the potential for cost-reducing design changes.

The competitive strategies that have been employed also may affect contractor pricing. Winner-take-all competitions were used for the electronics programs, thus providing the contractors with an incentive to bid low immediately. A winner-take-all competition generally occurs near the end of the production run. The program office awards all remaining production to the winner of a final competition. This incentive effect of a winner-take-all competition has been evidenced by a lower first unit price and slightly flatter price improvement rate for the second source compared to the initial source. Dual sourcing has been employed for the missile programs and the frigate program. In these cases, the continuous competition leads the second source to approach the cost of the initial source, as evidenced by a steeper price improvement rate.

3.2 FIRST SOURCE REACTION

As shown in Figure 3.1-2, the steeper second source price improvement rates exert pressure on the original producers. Research has indicated that the original producer reacts to this pressure by changing cost behavior.[2] Such behavior modification has been evidenced by a change in the original producer's price improvement curve.

An immediate drop in the initial producer's unit price has been observed as a break or downward "shift" of the price improvement curve. Continuing price reductions have been revealed as a steepening or "rotation" of the price improvement curve. These first source reactions to dual sourcing are shown graphically in Figure 3.2-1.

The observed price reactions by initial producers enable those producers to remain competitive with the second source throughout the remainder of the production run.

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[2]Kratz, Lou and Cox, Larry, "Analysis of AMRAAM Acquisition Alternatives: Phase II," The Analytic Sciences Corporation, TR-4049, May 1982.

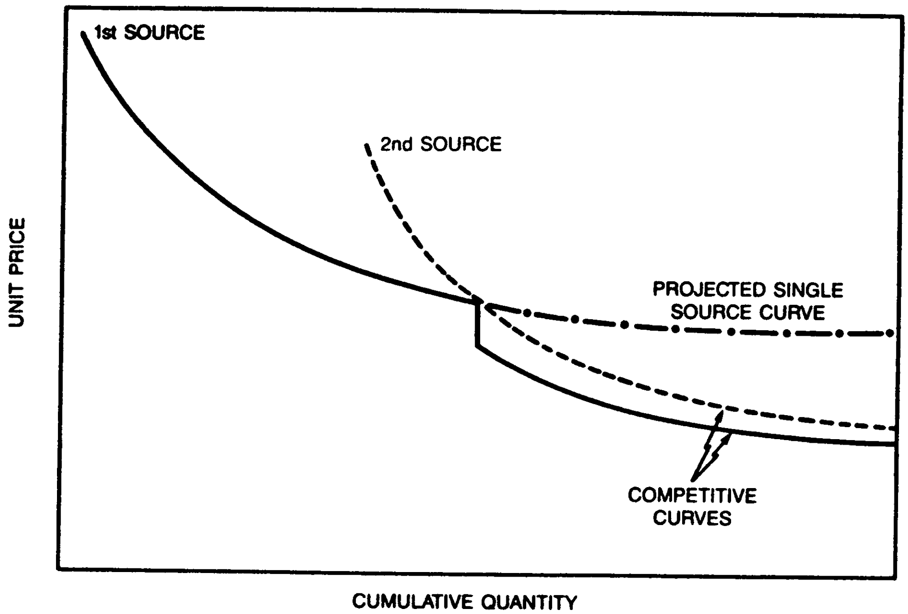

Figure 3.2-1 Initial Source Reactions to Dual Sourcing

Thus, competition drives both producers to more efficient pricing than previously demonstrated by the original manufacturer.

Preliminary research has indicated that the initial source attains the immediate price reduction, or downward "shift" by exercising greater control over cost elements that are billed as direct but are not related directly to manufacturing.[3] There also is evidence that the competitive pressures cause the previously single source producer to address "indirect" costs. The combined shift

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[3]"The Economics of Second Sourcing at the Prime Contractor Level in the Aerospace Industry," Trainor Associates, Inc., July 1983.

and rotation behavior has been observed on five tactical missile programs, as shown in Table 3.2-1.[4]

TABLE 3.2-1

FIRST SOURCE REACTIONS TO COMPETITION

PROGRAM	CONTRACTOR	SHIFT (%)	ROTATION (%)
AIM-7F	RAYTHEON	4	8
BULLPUP	MARTIN	14	13
TOW*	HUGHES	15	32
AIM-9B	G.E.	9	16
AIM-9L	RAYTHEON	10	7

*MULTIYEAR BUYOUT

3.3 RECENT PROGRAMS UNIT PRICE HISTORY

Behavior similar to that described in Sections 3.1 and 3.2 has been observed on recent programs. This section presents actual pricing behavior of two ongoing dual source programs.

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[4]Kratz, Louis A., et. al., Establishing Competitive Production Sources: A Handbook for Program Managers, The Defense Systems Management College, August 1984.

The Army's Hellfire missile unit price history is presented in Figure 3.3-1. As presented, Martin Marietta, the second source, attained early cost parity with Rockwell and won the major portion of the FY85 buy. Rockwell then reacted to this pressure by significant price reductions in FY86.

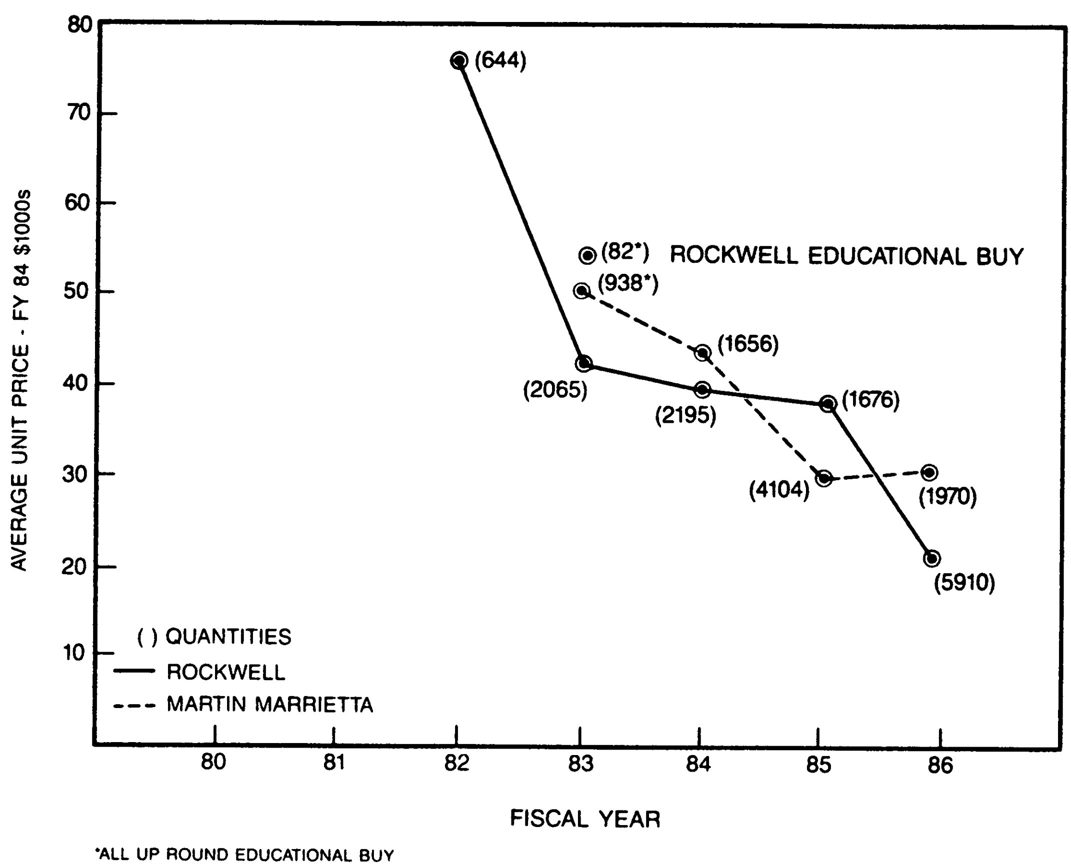

Figure 3.3-1 Hellfire Unit Price History

The Navy's Tomahawk missile unit price history is presented in Figure 3.3-2. As shown, McDonnell Douglas, the second source, was able to overcome the General Dynamics advantage and win the larger share of the FY87 buy.

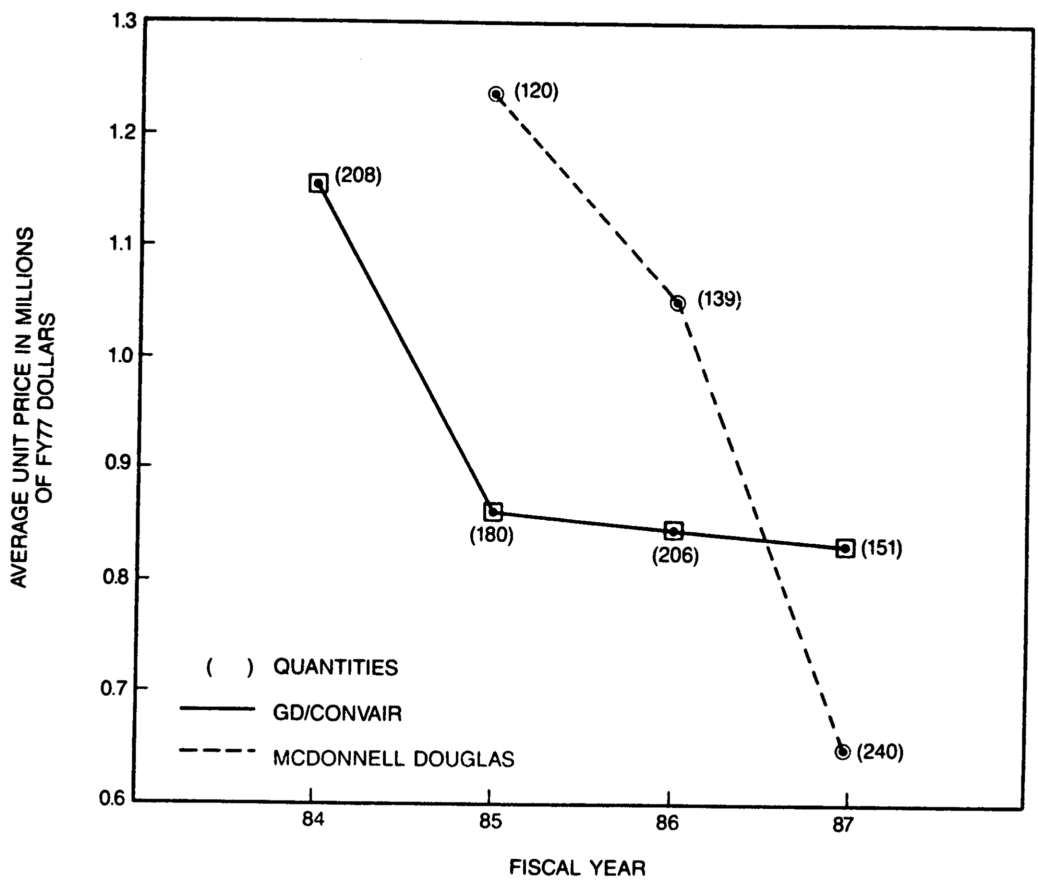

Figure 3.3-2 Tomahawk Unit Price History

The learning curve/production rate methodology, as developed in Chapter 2 and expanded in Chapter 3, will be employed in this study to analyze the effects of competition on contractor pricing. Following a discussion of the competitive procurement process in Chapter 4, the empirical results of the study will be presented.

CHAPTER 4

THE COMPETITIVE PROCUREMENT PROCESS

To begin the competitive procurement process, the program office releases a Request for Proposal (RFP) to the bidding contractors. The RFP includes contract clauses, specifications, the Statement of Work (SOW), instructions to offerors, the contract data requirements list (CDRL), warranty clauses, the government furnished equipment (GFE) list, and evaluation criteria.

Based on RFP instructions, the bidders prepare and submit their proposals. The proposals will include a bid pricing matrix, which is a matrix of proposed unit or total costs for a set of specific percentages of the lot.

The program office will evaluate the proposals, and determine the quantity split between the bidders. The quantity split is determined based upon the split award methodology being employed by the program office. Several split award methodologies have been employed within DoD.

This chapter presents a discussion of the competitive procurement process. Contractor bid formulation is discussed in Section 4.1. Split award methodologies are presented in Section 4.2. Section 4.3 discusses contractor behavior issues.

4.1 BID FORMULATION

In a competitive environment the contractor's primary goal is to win the largest share of each lot. This enables the contractor to keep its plant as close to full rate production as possible. To achieve this goal, the contractor will formulate its bid matrix based upon:

- An assessment of its competitor's potential pricing behavior
- The business climate of the contractor
- The split award methodology on which it expects the program office to base contract award
- General economic conditions.

The contractor will attempt to predict its competitor's pricing behavior. This prediction will be based on the competitor's pricing on the current program (if the current lot is not the first competitive lot), as well as the competitor's pricing behavior on prior, analogous programs.

The business climate of the contractor is also an important factor in the formulation of the bid matrix. If its plant is not operating at capacity, the contractor may bid lower than it would otherwise. If the contractor lost the current lot competition, it may submit an optimistically low bid in order to win the next lot.

The contractor also will take into consideration the split award methodology the government will employ in evaluating the bids. The RFP will indicate the split award methodology; however, it will not disclose specific parameter values that are associated with the methodology. For example, the RFP may state that an arc tangent formulation will be the basis for the split award; that is, the Solinsky method (Section 4.2.4) will be used. The RFP will not state the values of the A, B, and C parameters that are used in formulating the Solinsky model. In this situation, the contractor will formulate its bids such that it minimizes the midrange price and inflates the prices outside the midrange. Thus, the contractor structures its bids to reflect the split award methodology.

General economic conditions also influence the contractor's bid matrix. The existence of an employee union or a plant location in the Northeast indicates higher wages and correspondingly higher product prices. A high rate of inflation leads to higher wages and raw material prices, also leading to higher product prices. A decrease in the level of defense procurements will generally lead to an increase in product prices.[25]

4.2 SPLIT AWARD METHODOLOGIES

4.2.1 The Minimum Total Cost Rule

The minimum total cost rule involves solicitation of contractor prices for various percentages of the total lot buy. For example, lot prices for 20, 40, 50, 60, and 80 percent of the buy may be requested. The contractors' corresponding competing bids are summed for a total lot cost. The least cost combination determines the award percentages. Table 4.2-1 presents an example of the minimum total cost rule. As shown, the minimum total cost combination occurs when Contractor A receives 80 percent of the award and Contractor B receives 20 percent of the award.

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[25]Gansler, Jacques, S., The Defense Industry, MIT Press, Cambridge, Mass., 1980.

TABLE 4.2-1

EXAMPLE MINIMUM TOTAL COST RULE

Contractor A		Contractor B		
Percent of Buy	Bid Lot Cost	Percent of Buy	Bid Lot Cost	Total Lot Cost
80	28.8	20	7.7	36.5
60	21.7	40	15.2	36.9
50	18.1	50	19.0	37.1
40	14.3	60	22.7	37.0
20	7.3	80	30.1	37.4

The minimum total cost rule is subject to potential contractor gaming in that the contractors are presented with the opportunity to increase their bids on the smaller quantities. Such manipulation may result in award of the larger portion of production to the high cost bidder.[26] This can be demonstrated through a numeric example based upon the example shown in Table 4.2-1.

If Contractor B increases its lower quantity bids, a larger share of production would be awarded to Contractor B. For example, a ten percent increase in the proposed cost

[26]Elam, David W. and Paul Martin, "Requirements for Successful Implementation of a Competitive Dual Source Production Strategy," The Analytic Sciences Corporation, October 1980.

for 20 percent of the award and a five percent increase in the proposed cost for 40 percent of the award would result in Contractor B receiving 60 percent of the award. As shown in Table 4.2-2, the bid series does not appear unreasonable.

TABLE 4.2-2

MINIMUM TOTAL COST RULE BID MANIPULATION

Contractor A Percent of Buy	Contractor A Bid Lot Cost	Contractor B Percent of Buy	Contractor B Bid Lot Cost	Total Lot Cost
80	28.8	20	8.5	37.3
60	21.7	40	16.0	37.7
50	18.1	50	19.0	37.1
40	14.3	60	22.7	37.0
20	7.3	80	30.1	37.4

4.2.2 Weighted Average Cost Rule

Like the minimum total cost rule, the weighted average cost rule involves solicitation of lot prices for the various percentages of the annual buy. This method then weights each bid and sums the corresponding competing amounts for a total lot cost. The weights are determined by the program office. Low quantities receive the highest weights, which helps lessen the effects of contractor gaming. The least cost combination determines the award percentages. Table 4.2-3 presents an example of the

TABLE 4.2-3

EXAMPLE WEIGHTED AVERAGE COST RULE

Contractor A			Contractor B			Total Weighted Lot Cost
Percent of Buy	Bid Lot Cost	Weight	Percent of Buy	Bid Lot Cost	Weight	
80	28.8	0.1	20	7.7	0.4	6.0
60	21.7	0.1	40	15.2	0.2	5.2
50	18.1	0.2	50	19.0	0.2	7.4
40	14.3	0.2	60	22.7	0.1	5.1
20	7.3	0.4	80	30.1	0.1	5.9

weighted average cost rule. Note that proposed costs are identical to those used in Table 4.2-1.

The minimum weighted cost combination occurs when Contractor A receives 40 percent of the award and Contractor B receives 60 percent of the award. As shown, this method results in a completely different award outcome than the minimum total cost rule, even when identical proposed costs are used. In this example, the outcome was driven solely by the weighting scheme.

This method limits the potential for contractor gaming by varying the weighting factors for each competition; however, there is still potential for contractor gaming. As in the minimum total cost rule, contractors have the opportunity to raise their bids on lower quantities in an attempt to make their bids on higher quantities relatively more attractive.

To limit contractor gaming and to equalize the solicited bids, the weight factors could be altered annually. A scheme that heavily weights the lower percentage bids counteracts a bid structure that favors higher percentage splits that are more attractive relative to the lesser amounts.

4.2.3 MICOM Approach

Another method to inhibit the effects of contractor gaming is the MICOM approach, developed by the Army Missile Command and used successfully on the Hellfire missile. Lot prices are solicited from each contractor for various percentages of the annual buy. From these proposed prices, an average unit cost for each contractor is calculated. The average unit cost of each contractor is used to determine the percent differential between the contractors. The differential then determines the percentage awarded to each contractor. Equation 4.2-1 is used to calculate the bid price percent differential.

$$\frac{\text{Highest AACB} - \text{Lowest AACB}}{\text{Lowest AACB}} \times 100 = \begin{array}{c}\text{Percent}\\ \text{Differential}\end{array} \qquad (4.2\text{-}1)$$

where:

AACB = Average Adjusted Contractor Bid.

Tables 4.2-4 and 4.2-5 present an example of the MICOM approach.

As presented in Table 4.2-5 the 2.30 percent difference in the overall average unit costs results in an award split of 50 percent to each contractor, based on the split matrix presented in Table 4.2-4.

The MICOM approach limits potential contractor gaming more than the minimum total cost and weighted average cost rules. The contractor will not know its competitor's AACB, and will be unable to game its bids such that the AACB falls in a specific percent differential range. The bid structure may be manipulated by a contractor to offer a more competitive average price. Unless the contractor reduces all bid prices the cost of the gamed lot will be higher than the comparable nominal bid.

TABLE 4.2-4

EXAMPLE MICOM PRODUCTION SPLIT MATRIX

Percent Differential Range	Percent Awarded to Low Bidder	Percent Awarded to High Bidder
0 ≤ 3	50	50
3 ≤ 8	55	45
8 ≤ 15	60	40
15 ≤ 30	70	30
30 ≤ 50	71	29
50 ≤ 60	72	28
60 ≤ 75	73	27
75 ≤ 100	75	25

TABLE 4.2-5

EXAMPLE MICOM APPROACH

Contractor A			Contractor B		
Percent of Lot Buy	Bid Lot Cost	Average Unit Cost	Percent of Lot Buy	Bid Lot Cost	Average Unit Cost
80	29.1	90.8	20	7.5	94.2
60	21.9	91.1	40	15.0	93.6
50	18.3	91.3	50	18.7	93.3
40	14.6	91.5	60	22.3	93.1
20	7.4	91.9	80	29.6	92.6
AACB		91.3			93.4
Percent Differential		2.30			

4.2.4 Solinsky Rule

Another quantity allocation technique developed by the Army involves solicitation of contractor bids for various quantities and calculation of midpoint bid prices. These prices are used as inputs to an arc tangent formulation that determines the production split. This method is referred to as the Solinsky rule.[27]

The Solinsky rule was developed to enhance aggressive bidding by awarding percentage shares of production based upon the difference in bid prices for a midrange quantity. If the differential between two contractors' bids is large, the percent share differential is large. Similarly, if the bid differential is small, the percent share differential is small. The bid differential is calculated as shown in equation 4.2-2.

$$\frac{\text{Company B Price} - \text{Company A Price}}{\text{Company B Price} + \text{Company A Price}} = \text{Bid Differential} \qquad (4.2\text{-}2)$$

---

[27]Solinsky, Kenneth D., "Controlled Competition for Optimal Acquisition," Defense Systems Management Review, Volume 3, Number 2, Spring 1980.

The bid differential is calculated for the midrange quantity only. As an example, if the annual quantity equals 400 items and bids were solicited for 30, 50, and 70 percent of the total buy, the bid differential would be calculated for the 50 percent amount only. The percentage share of production for Company A then is calculated according to an arc tangent formulation. The arc tangent function is shown in equation 4.2-3.

$$\left[\frac{Ax}{|x|} \left(\frac{\arctan B|x|^{C}}{90} \right) + 1 \right] 50\% = \text{Percent of procurement quantity for Company A} \qquad (4.2\text{-}3)$$

where:

x = bid differential

A,B,C = Constants used to modify the shape and placement of the arc tangent function.

The values of A, B, and C are assigned by the program office. Company B is awarded the remainder of the lot quantity. An example formulation is presented in Figure 4.2-1, representing two annual buys of 400 items derived from different initial price improvement rates.

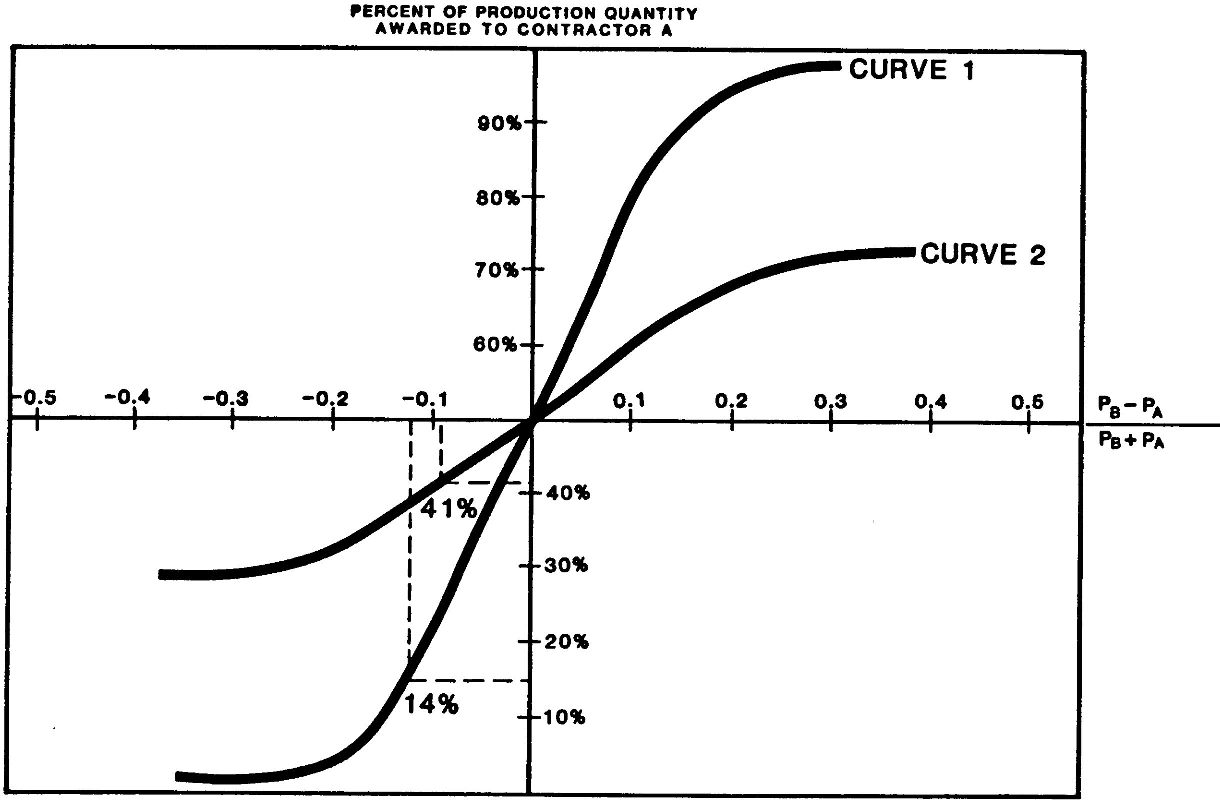

Figure 4.2-1 Example Solinsky Rule

As shown in Figure 4.2-1, the Solinsky rule can be portrayed as a four-quadrant diagram. The ratio of Contractor B's bid to Contractor A's bid is presented along the X-axis. The percent of the production buy awarded to Contractor A is shown along the Y-axis. A family of arc tangent curves, similar to curves 1 and 2 in Figure 4.2-1, can be generated by the program office by varying the constants associated with the arc tangent function.

As shown, the possible award outcome can vary significantly depending on the particular arc tangent function that is chosen. In the example, curve 1 yields an award of 14 percent to Contractor A with the remaining 86 percent awarded to Contractor B. Curve 2, using a different arc tangent function, yields a 41 percent award to Contractor A and the remaining 59 percent to Contractor B. A particular function would be selected prior to RFP release.

The Solinsky rule limits the potential problems associated with the minimum total cost and weighted average cost rules; however, it also is susceptible to contractor gaming. This is due to its reliance on a single midrange price. The method presents an incentive to the contractors to minimize the midrange price and to inflate prices outside the midrange. This is particularly attractive to the contractors because the actual award probably will be outside the midrange.

4.2.5 <u>Pelzer Rule</u>

The effect of price competition on product quality is an area of great concern. It has been argued that price competition forces a trade-off between cost and quality, often leading to reduced system performance. Pelzer has developed an allocation technique that reduces this risk by incorporating quality and other relevant performance factors into the award formulation.[28] In addition, the technique incorporates an index weighting system that reflects relative price decreases over a three-year period.

The technique involves requesting bids from both contractors for various production quantities. The bid prices then are fit to a quadratic equation to reflect the effect of production rate variations on unit costs. Average unit costs are calculated for both contractors and then input into the selection formula.

The selection formula includes other factors such as mean time to repair, timeliness of delivery, and mean flight hours between failure, measured as achieved performance versus desired performance. The factors are weighted according to their relative program importance. Mathematically, competitive factors are calculated as shown in equation 4.2-4.

$$F_X = 1 + (W_X (1 - \frac{R_X}{S_X})) \qquad (4.2\text{-}4)$$

---

[28]Pelzer, Jay L., "Proposed Allocation Technique for a Two-Contrator Procurement," Air Force Institute of Technology, May 1979.

where:

W_x = the weight assigned to factor X

R_x = the achieved contractor performance for factor X

S_x = the specified standard for factor X.

The Pelzer rule for calculating the annual competitive index can be expressed as shown in equation 4.2-5.

$$I_a = (P_a)\ (F_1)\ (F_2)\ (F_3)\ \ldots\ (F_n) \qquad (4.2\text{-}5)$$

where:

I_a = the annual total competitive index for contractor A

P_a = the average unit line price bid for contractor A

F_1 through F_n are all other competitive factors to be considered.

The annual index is used to calculate an overall competitive index for the contractor that reflects the contractor's competitive behavior in the prior two years of production. Mathematically, the index is calculated as shown in equation 4.2-6.

$$\text{Overall Index} = I_{a,n} \times \frac{I_{a,n}}{I_{a,n-1}} \times \frac{I_{a,n-1}}{I_{a,n-2}} \qquad (4.2\text{-}6)$$

The ratio of the two contractors' overall competitive indices is used to determine the production quantity split. Table 4.2-6 is an example of the Pelzer rule.

TABLE 4.2-6

EXAMPLE PELZER RULE PERFORMANCE FACTORS

Performance Factors	Specified Achievement Standards	Factor Weights	Contractor A Achieved Performance	Contractor B Achieved Performance
Range	500	0.50	400	500
Delivery Schedule	12	0.15	12	12
Weight	15	0.20	20	15
Thrust	3200	0.15	3200	3200

Table 4.2-7 shows the results of an award of 400 items in the third year of competition based on the figures in Table 4.2-6. Contractor B achieved all performance requirements, while Contractor A did not in two key areas. Contractor A also has bid less competitively in the past and on the current production contract. Thus, Contractor B received 54 percent of the annual award.

TABLE 4.2-7

EXAMPLE PELZER RULE

Element	Contractor A	Contractor B
Average Unit Price (P_a)	0.09	0.09
Factors Value ($F_1 ... F_n$)	1.15	1.00
Annual Index ($I_{a,n}$)	0.10	0.09
Overall Index	0.11	0.08
$I_{a,n-1}$	0.11	0.09
$I_{a,n-2}$	0.11	0.10
Quantity Awarded	184 (46%)	216 (54%)

The Pelzer rule presents several advantages over prior allocation techniques. Contractor gaming is limited by the three-year, moving-average index. High prices or poor performance over the past three years will decrease the quantity awarded to the contractor. Conversely, improved performance and decreased prices will increase the quantity awarded. In addition, the inclusion of critical factors other than price reduces the risk of late deliveries or poor performance. The ability to alter the weighting scheme for each production lot award allows the program office to focus on problem areas if any are experienced on prior subsystems.

The Pelzer approach is relatively complex; however, it is not immune to contractor bid manipulation. Pelzer describes several ways in which the technique can be gamed. For example, if a contractor perceives a high percentage of the award could be won by bidding a certain average unit cost, the bids may be manipulated to obtain such a figure. The lower percent bids could be reduced and the higher percent bids increased to maintain the same average bid.

4.2.6 The PRO Concept

The Profit Related to Offer (PRO) Concept was developed by the Navy Strategic Systems Program Office (SSPO) for use during competitive production of portions of the guidance system for the Trident and Poseidon programs. This method emphasizes product quality beyond a minimum acceptable level while encouraging efficient production. To avoid the potential low quantity bidding games associated with other techniques, both contractors receive 50 percent of the production award.

The concept can be summarized as the following six steps:

- The program office determines a competitive price range for the item based on a shouldcost estimate and design-to-cost goals, and historical data

- Both contractors are asked to submit target cost bids for 50 percent of the annual buy

- If the bids are within the competitive range, the low cost bidder is the winning contractor and is awarded a fixed price incentive contract at the proposed target cost. The contract includes a predetermined target profit and a predetermined share line

- The high cost bidder is awarded a fixed price incentive contract at the bid target cost if the bid is within five percent of the winning contractor's bid. A target profit is determined based upon the dispersion of the two bids

- If the high bidder's proposed target cost is greater than five percent of the winning contractor's bid, target cost is determined by weighted profit guidelines

- Share line relationships between target cost and contract ceiling are determined by a random procedure, to deter contractor gaming.

As discussed, the high bid contractor's target profit is determined based upon the dispersion of the bids. An example profit formula is given by equation 4.2-7.

$$
P_L = \begin{cases} \text{Profit Zone 1: If } 1 < L/W \leq 1.05, \text{ then } 0.12 \times W - 0.6(L-W) \\ \text{Profit Zone 2: If } 1.05 < L/W \leq 1.15, \text{ then } 0.075 \times W - 0.1(L-W) \\ \text{Profit Zone 3: If } 1.15 < L/W, \text{ then } 0.04625 \times W \end{cases} \quad (4.2\text{-}7)
$$

where:

L = Bid cost of losing contractor

W = Bid cost of winning contractor

P_L = Target profit of losing contractor.

The profit "zones" associated with the PRO concept are illustrated in Figure 4.2-2. As shown, percent profit for the higher bid contractor decreases linearly as the bid differential increases.

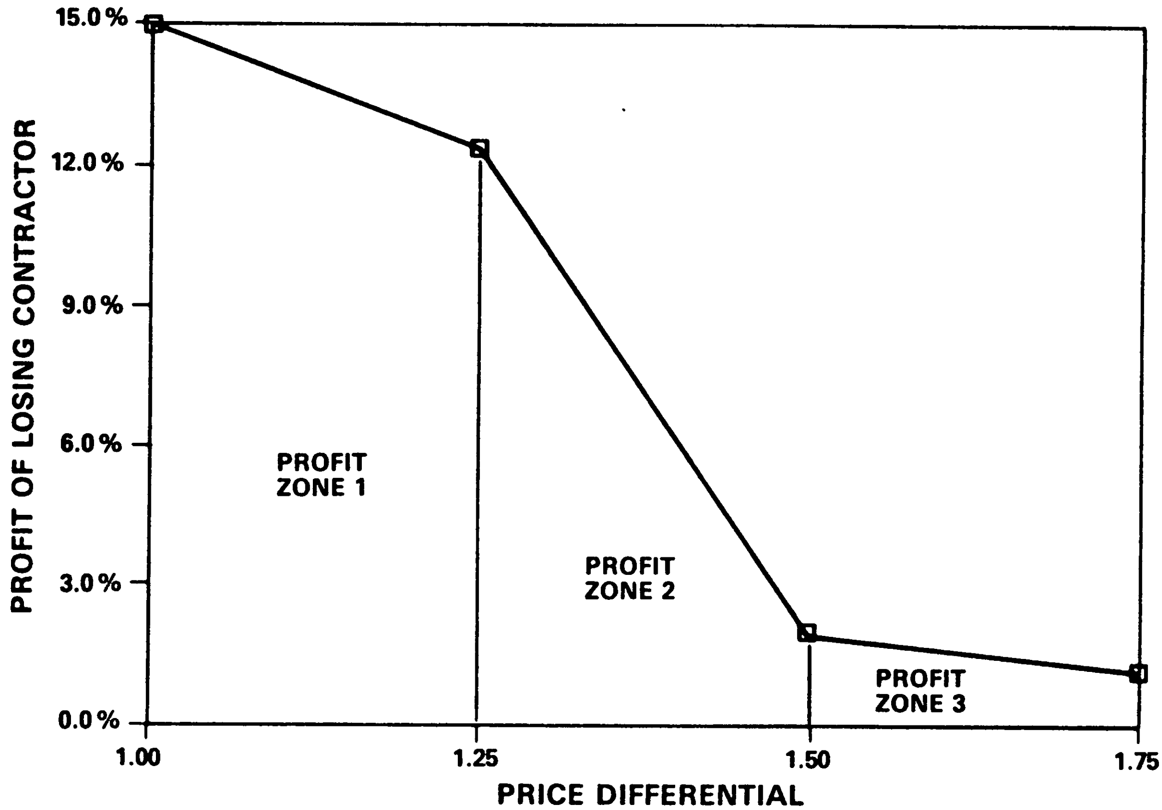

Figure 4.2-2 PRO Concept Profit Formulation

As presented, there are significant profit penalties for the losing contractor if the loser's bid is significantly higher than the winner's bid. Table 4.2-8 presents an example of the PRO concept.

TABLE 4.2-8

EXAMPLE PRO CONCEPT

Contractor	Bid	Differential	Profit
Contractor A	18.3	1.02 - Zone 1	15.0%
Contractor B	18.6		12.1%

Contractor B bid higher yet within the desired competitive range, thus, Contractor A received full profit as the winning contractor and Contractor B received a smaller profit percentage.

4.3 CONTRACTOR BEHAVIOR ISSUES

A major concern regarding the competitive procurement process is that it will lead to noncompetitive or gaming behavior on the part of contractors. If present, this behavior can be inferred from the contractor's pricing data.

Noncompetitive behavior, or tacit collusion, occurs when the number of sellers in the market is small, and they recognize their mutual interdependence. As Chamberlin observed:

> If each seeks his profit rationally and intelligently, he will realize that when there are only two or a few sellers his own move has a considerable effect upon his competitors, ... and although the sellers are entirely independent, the equilibrium result is the same as though there were a monopolistic agreement between them.[29]

As shown in Figure 4.3-1, noncompetitive behavior does not begin until year 5. In years 2 through 4, the contractors are competing effectively. Unit prices decline over the three lots. The second source is able to overcome the first source advantage by year 4 to win the lot. In years 5 through 7, unit prices flatten rather than decline. The price/quantity combinations for the contractors are virtually the same. This implies that their bids were very close for each lot.

The contractors engage in this behavior because they can no longer afford to compete. Further competitive price cuts either will not allow them to make a minimum profit level (as directed by corporate headquarters), or will not allow them to cover the costs of producing the lot.

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[29]Chamberlin, E.H., The Theory of Monopolistic Competition, Harvard University Press, Cambridge, Mass., p. 48, 1933.

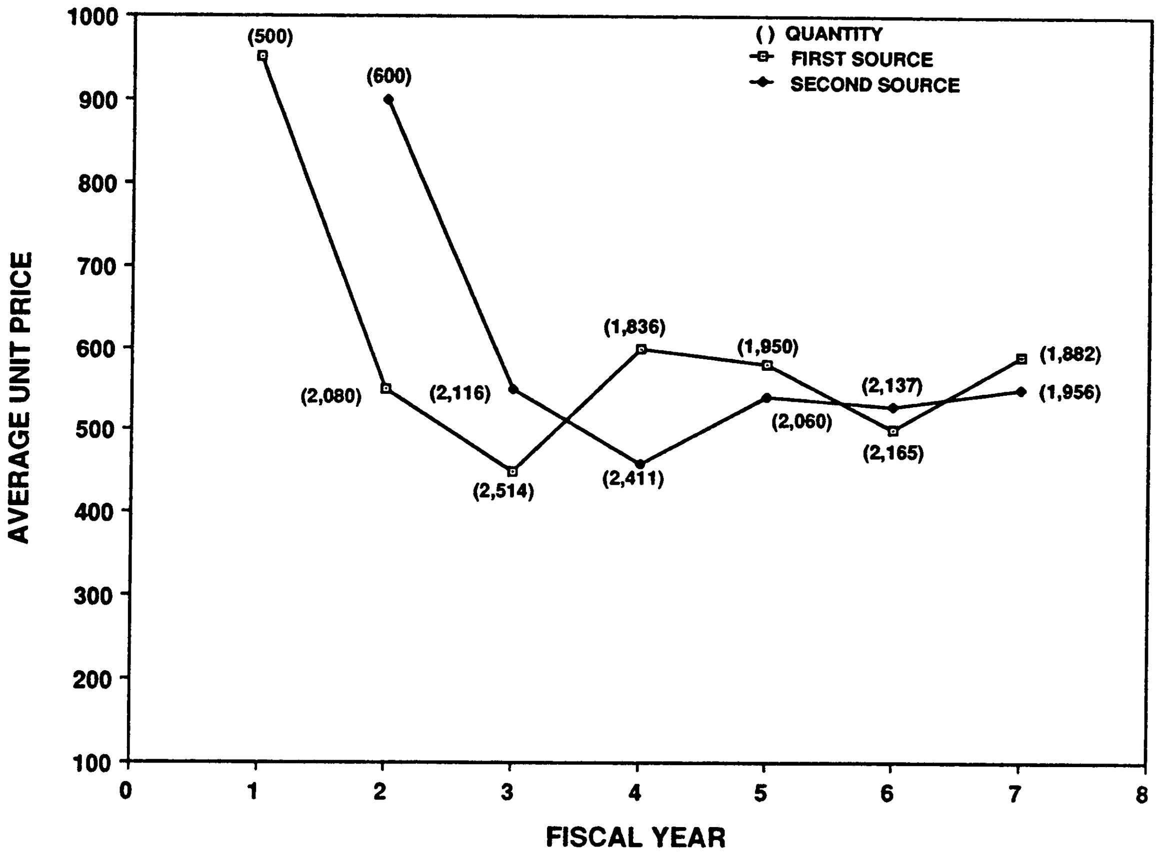

Figure 4.3-1   Example Noncompetitive Behavior

Figure 4.3-1 could be an example of either explicit or tacit collusion. Unless the contractors admitted to explicit collusion, it would not be possible to determine which had occurred. However, as no "serious study of the defense industry" has concluded that contractors engage in explicit collusion,[30] one must assume that tacit collusion has occurred.

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[30]Gansler, Jacques, S., The Defense Industry, MIT Press, Cambridge, Mass., p. 72, 1980.

Gaming occurs when the contractor formulates its bids with the intention of trying to force a specific quantity split. For example, the contractor may increase its bids on the lower quantities in order to make its higher quantity bids relatively more attractive. Then should the contractor lose the major portion of the lot, it will make a greater profit and sustain a higher cost structure on the smaller quantity than it would have otherwise. Figure 4.3.2 presents an example of gaming behavior.

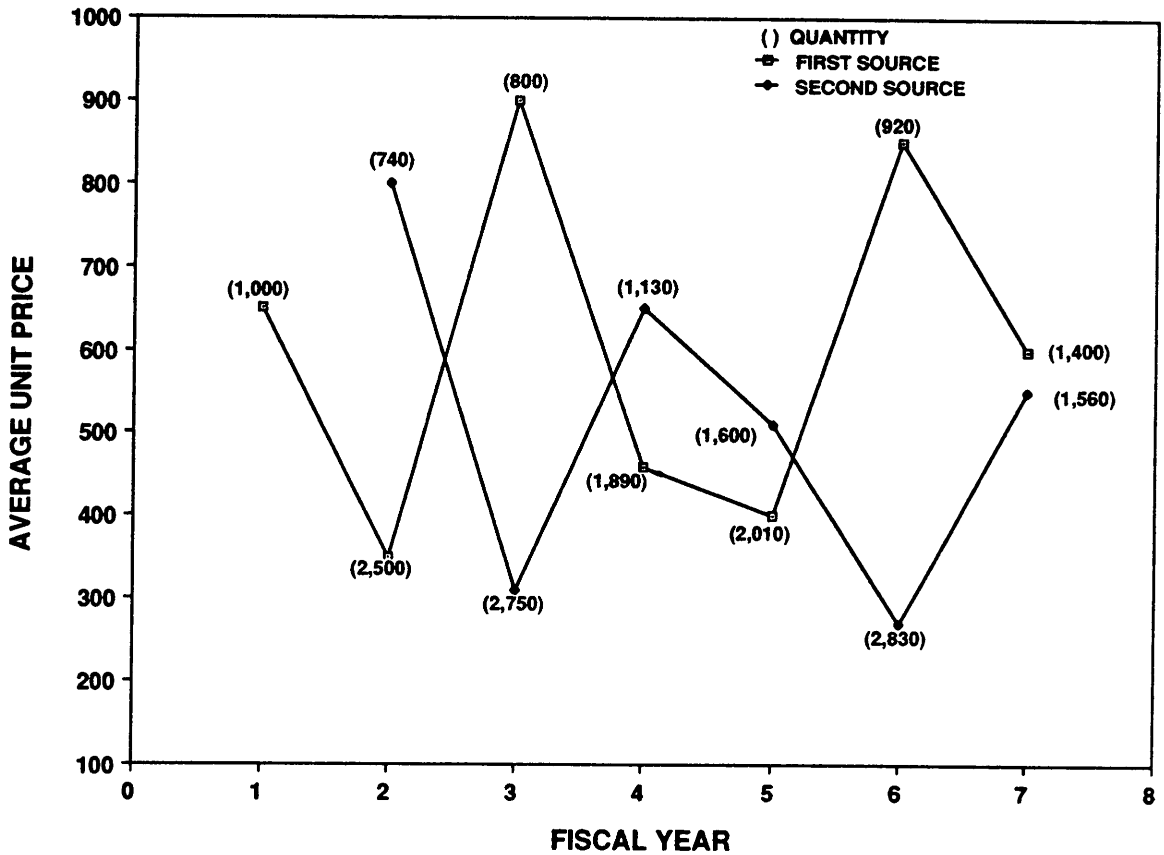

Figure 4.3-2 Example Gaming Behavior

In year 3, the first source produces 800 units at $900 per unit. Some of this price increase from year 2 is due to rate adjustment to a lower production quantity. However, note that the first source's price in year 3 is $100 per unit greater than the second source's price on 740 units in year 2 (the second source's first production lot). This is indicative of gaming by the first source. The same situation occurs in year 6. The first source's price increase is too great to be attributed wholly to rate adjustment.

As shown in Section 4.2, gaming techniques differ for each split award methodology. This is the primary reason the government may chose not to disclose the split award parameters in the RFP. It is much more difficult to successfully game bids when the parameters are unknown.

CHAPTER 5

AIM-9M SIDEWINDER PROGRAM OVERVIEW

The effects of competition on contractor pricing behavior, as discussed in Chapters 3 and 4, will be investigated in this study based upon data from the AIM-9M Sidewinder missile program. The Sidewinder program is a joint service (Air Force/Navy) effort. The Sidewinder is an infrared homing missile designed to increase operational performance against infrared countermeasures. It is used in short range air-to-air combat. The Sidewinder is 113 inches in length, has a diameter of 5 inches, and weighs 188 pounds. The Sidewinder is illustrated in Figure 5-1.

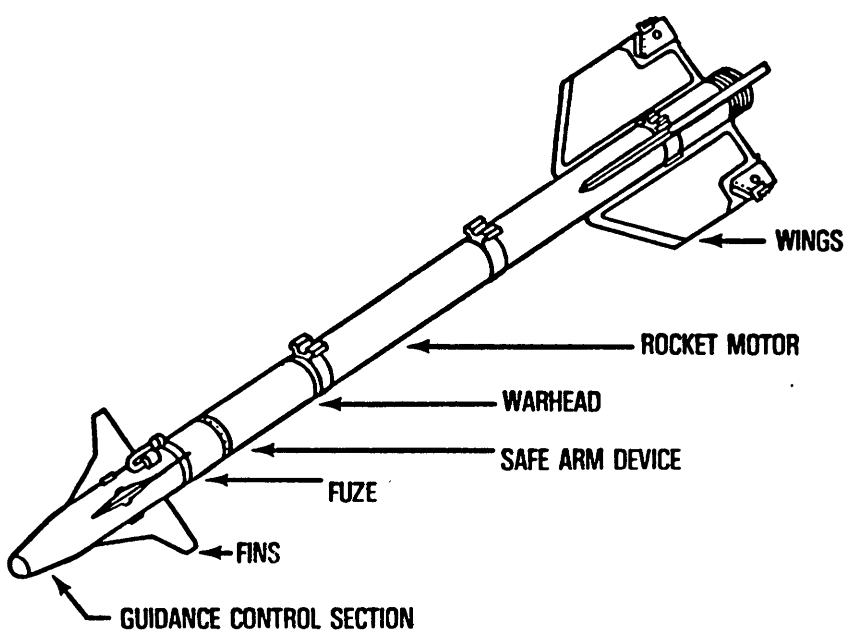

Figure 5-1 AIM-9M Sidewinder Missile

5.1 SIDEWINDER SPLIT AWARD METHODOLOGY

The split award methodology employed on the Sidewinder program is a modified form of the minimum total cost rule. Price is the primary selection criteria; however, certain contractor performance issues are considered. These include performance of the contractor's fielded units, production difficulties, and schedule slippages.

To begin the source selection process the program office releases the RFP, soliciting contractor bids for various portions of the total lot. For example, bids on 1000, 2000, 3000, and 4000 units may be solicited for a lot of 4000 units.

The program office plots the contractor bids to see if, and where, the bid curves intersect. The intersection is considered the least price combination. If the program office approves of this combination, and if neither contractor has performance problems which would interfere with its production, contracts are awarded.

Should either contractor have performance problems, the program office may award other than the least price combination. For example, if a contractor has been unable to meet its delivery schedule for the previous lot, a portion of that contractor's quantity may be awarded to its competitor. If the program office feels that one or both contractors have bid too high, prices are negotiated.

5.2 STUDY DATA

The data used in this study were obtained from the AIM-9M Sidewinder program office. Five dual source subsystems of the Sidewinder were considered:

- Guidance Control Section
- Safety Arming Device
- Warhead
- Active Optical Target Detector
- Rocket Motor.

CHAPTER 6

EMPIRICAL RESULTS

To investigate the effects of competition on the pricing behavior of defense contractors, contract award data for five subsystems of the AIM-9M Sidewinder missile were analyzed. The data were graphed and examined for evidence of noncompetitive and/or gaming behavior. Next, the data were run on the TASC Rate model (Section 2.3) in order to estimate the first unit price, price improvement rate, and production rate parameter for each contractor.[31] Finally, the first source data for the Guidance Control Section (GCS) and the Active Optical Target Detector (AOTD) were run on the TASC Learning Curve, Production Rate, and Competition (LCPRC) Model (Section 6.1) to determine first source competitive first unit price and price improvement rate, and percent shift and rotation of the price improvement curve. The results of the study are presented in Sections 6.1 through 6.5.

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[31]The TASC Rate Model parameters were estimated using the SORITEC software package, which uses the Gaussian method of nonlinear estimation.

6.1 GUIDANCE CONTROL SECTION

The GCS is produced by the Raytheon Company (first source) and Ford Aerospace. Ford began production with a directed buy of 1200 units in 1982. Competitive bidding began in 1983. The Raytheon and Ford pricing data are displayed in Figure 6.1-1.

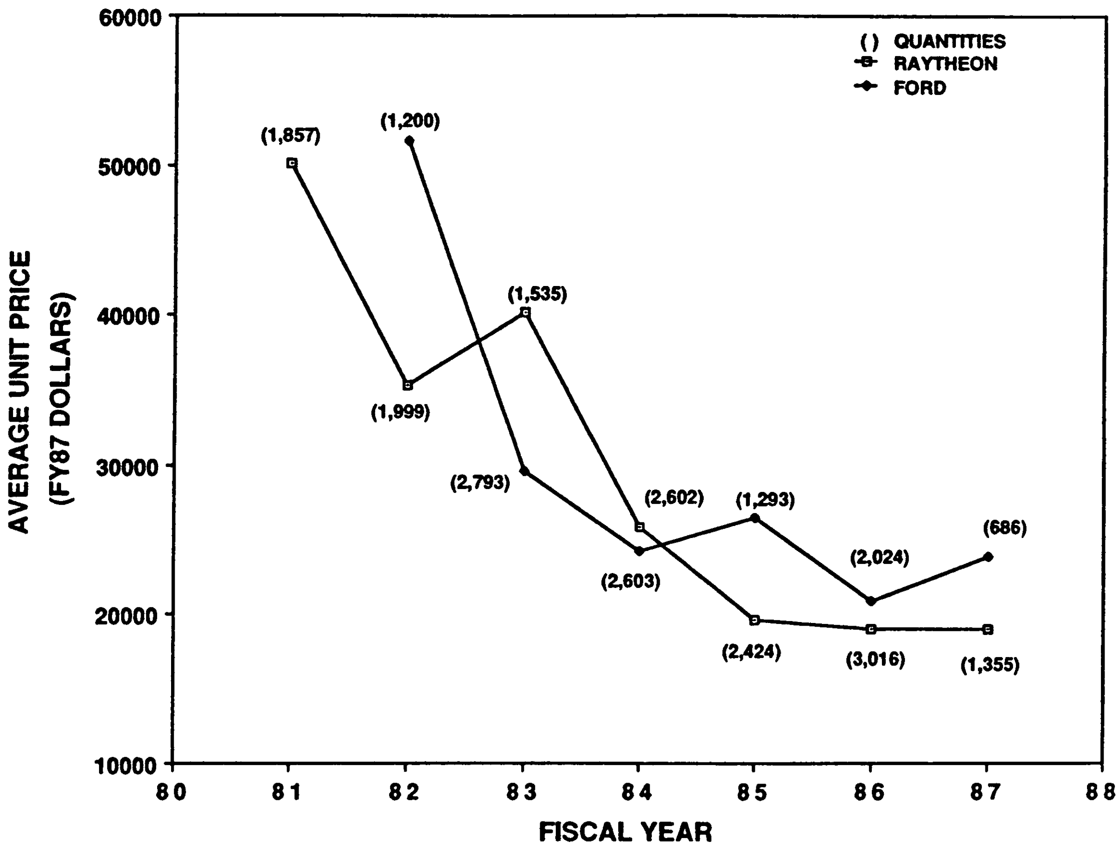

Figure 6.1-1 AIM-9M Guidance Control Section

The parameters that have been developed using the TASC Rate model are presented in Table 6.1-1.

TABLE 6.1-1

AIM-9M GCS PARAMETER ESTIMATES*
(FY87 Dollars)

	FIRST UNIT PRICE	PRICE IMPROVEMENT RATE	PRODUCTION RATE PARAMETER	$\bar{R}^2$	SUM OF SQUARED ERRORS
Raytheon	$219,115	.83 (-5.54)	.74 (-1.59)	.818	315.65
Ford	$211,292	.84 (-16.10)	.92 (-2.66)	.992	12.79

*T-statistics in parentheses

Tables 6.1-2 and 6.1-3 present the parameter estimates' associated percent error.

TABLE 6.1-2

RAYTHEON GCS PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	1857	50,093.0	51,863.9	-3.54
82	1999	35,329.0	33,566.6	4.99
83	1535	40,154.0	33,081.4	17.61
84	2602	25,832.0	23,865.7	7.61
85	2424	19,626.0	22,639.4	-15.35
86	3016	18,985.0	19,235.4	-1.32
87	1355	18,954.0	26,126.7	-37.84

TABLE 6.1-3

FORD GCS PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Predicted	Percent Error
82	1200	51,654.0	52,051.0	-0.76
83	2793	29,587.0	29,268.9	1.08
84	2603	24,154.0	24,311.9	-0.65
85	1293	26,509.0	24,470.7	7.69
86	2024	20,889.0	21,945.9	-5.06
87	686	23,862.0	24,272.3	-1.72

The GCS data imply that both Raytheon and Ford competed aggressively, prices decreasing over the seven lots. The Raytheon and Ford price improvement rates are fairly steep, indicating that they are both very price responsive to the increase in cumulative quantity over the seven lots. The Raytheon production rate parameter is much steeper than the Ford parameter. This indicates that Raytheon is far more price sensitive to changes in lot quantities than Ford. Test statistics are strong for both regressions, and the parameter signs are negative.

Competitive bidding began in lot three. Ford surprised Raytheon by immediately overcoming the Raytheon competitive advantage to win the lot. Raytheon had a small rate adjustment price increase for its portion of the buy. Raytheon and Ford split lot four. Ford's price was $1680 per unit below Raytheon's price.

Having lost two consecutive lots, Raytheon bid aggressively and won lot five. Ford had a small price increase due to rate adjustment. Lot six showed small but continuing price decreases. In lot seven a large lot quantity decrease had little effect on the contractor's prices, because the lot was produced on a shortened production run.

The Raytheon data also were run on the TASC LCPRC model. LCPRC is similar to the Rate model; however, it also identifies the first source shift and rotation parameters, competitive first unit price and competitive price improvement rate. These parameters are illustrated in Figure 6.1-2.

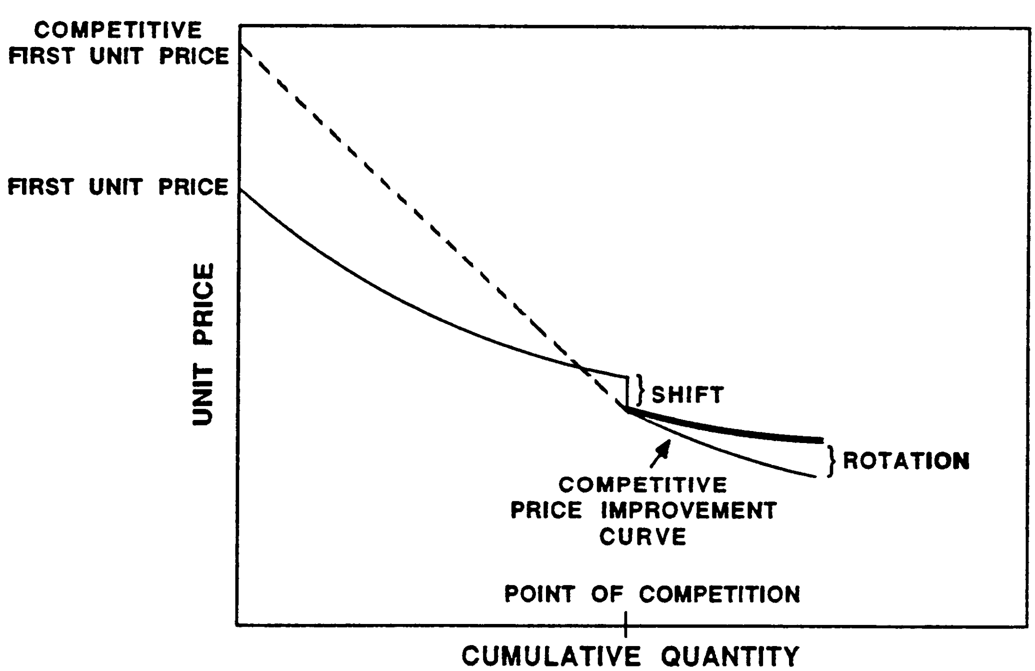

Figure 6.1-2 LCPRC Parameters

LCPRC inputs are unit price, corresponding lot quantity, production rate, and point of competition. From these inputs, LCPRC simultaneously estimates the five parameters using equation 6.1-1.

$$Z = A_o X_o^{B_o} A_1 X_1^{B_1} Y^C \qquad (6.1\text{-}1)$$

where:

Z = unit price of the x^{th} item produced

A_o = a constant, referred to as the first unit price

X_o = cumulative quantity produced up to the point of competition

B_o = coefficient which describes the slope of the pre-competition quantity/price curve, defined as the ln (price improvement rate)/ln (2)

A_1 = a constant, referred to as the competitive first unit price

X_1 = cumulative quantity produced beginning after the point of competition

B_1 = coefficient which describes the slope of the competitive quantity/price curve, defined as the ln (price improvement rate)/ln (2)

Y = production rate in effect

C = coefficient which describes the slope of the rate/price curve, defined as the ln (production rate)/ln (2).

Like the Rate model, LCPRC is estimated using a weighted least-squares estimation of the nonlinear function based on a generalization of Newton's method for finding the roots of an equation.

As illustrated above, LCPRC splits the price improvement curve at the point of competition. The point of competition occurs when the first source reacts to the price pressure exerted by the second source, in order to remain competitive with the second source for the remainder of the production run. As explained in Section 3.2, the first source reacts with a downward shift in its price improvement curve, followed by a downward rotation of the curve. These are the shift and rotation parameters calculated by LCPRC. The two first unit price parameters are calculated by driving their respective price improvement curves back to the price axis.

In the Rate model, all price changes are attributed to learning (price improvement) and production rate effects. It does not distinguish between price decreases caused by competition and price decreases caused by learning. LCPRC isolates the effects of competition on prices by calculating shift and rotation and then estimating the resulting competitive price improvement curve. This allows comparison of the first source's pre-competitive and competitive price improvement curves. Price decreases in the pre-competition phase result from learning. The additional price decreases in the competitive phase result from competition, as evidenced by the shift and rotation of the first source's price improvement curve. These price decreases which caused the shift and rotation of the curve would not have occurred in a single source environment.

The question will arise as to why the Rate model was used if LCPRC is more comprehensive. This was done for two reasons. First, to build the case that competition does affect contractor pricing behavior. The Rate model regression results were strong overall, with the differential between the actual and predicted values of unit price less than ten percent in most cases. LCPRC provided even smaller percent errors, which indicates that the added independent variables provided further "explanation" of unit price.

The second reason for utilizing the Rate model is that it allows comparison of first source and second source parameters for the total program. LCPRC and Rate model parameters cannot be compared as they are not calculated in the same way.

LCPRC was run only for the GCS and AOTD. These are complex electronic systems, with a great potential for learning (price) improvement effects. The warhead, rocket motor, and safety arming device (SAD) are simple systems with relatively mature technologies. They do not have the potential for learning effects that the more complex GCS and AOTD do.

The following parameters were developed for Raytheon on the LCPRC model:

- First Unit Price = $138,431 (FY87 Dollars)
- Price Improvement Rate (FY81-FY83) = .89
- Competitive Price Improvement Rate (FY84-FY87) = .70
- Production Rate Parameter = .89
- Percent Shift = 13.54
- Percent Rotation = 21.43.

Table 6.1-4 presents the parameter estimates' associated percent error.

TABLE 6.1-4

RAYTHEON LCPRC PARAMETER ESTIMATES PERCENT ERROR (FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	1857	50,093.0	49,690.9	0.80
82	1999	35,329.0	37,957.8	-7.44
83	1535	40,154.0	36,384.1	9.39
84	2602	25,832.0	25,201.1	2.44
85	2424	19,626.0	21,546,4	-9.79
86	3016	18,985.0	18,163.3	4.33
87	1355	18,954.0	18,962.2	-0.04

The sum of squared errors for the regression was 26.05.

The LCPRC results show that Raytheon reacted to the price pressure exerted by Ford with a drop in unit prices, as evidenced by the 13.54 percent shift in its price improvement curve. Continuing price reductions are evidenced by the 21.43 percent rotation of the curve. Raytheon's competitive price improvement rate of .70 is much steeper than its pre-shift rate of .89. The steeper price improvement rate allows Raytheon to remain competitive with Ford through the remainder of the competitive phase. The production rate parameter of .89 indicates that Raytheon is somewhat price sensitive to changes in lot quantity. Prior missile programs have been relatively insensitive to production rate changes, demonstrated by the historical range of production rate parameters of .95 to 1.00.[1]

6.2 SAFETY ARMING DEVICE

The SAD is produced by Piqua Engineering (first source) and Micronics, Inc. Competitive bidding began in 1982. There were no directed buys. The Piqua and Micronics pricing data are displayed in Figure 6.2-1.

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[1]Bohn, Michal and Kratz, Louis A., "Analysis of Production Rate Effects on Unit Costs," The Analytic Sciences Corporation, EM-228-WA, January 1984.

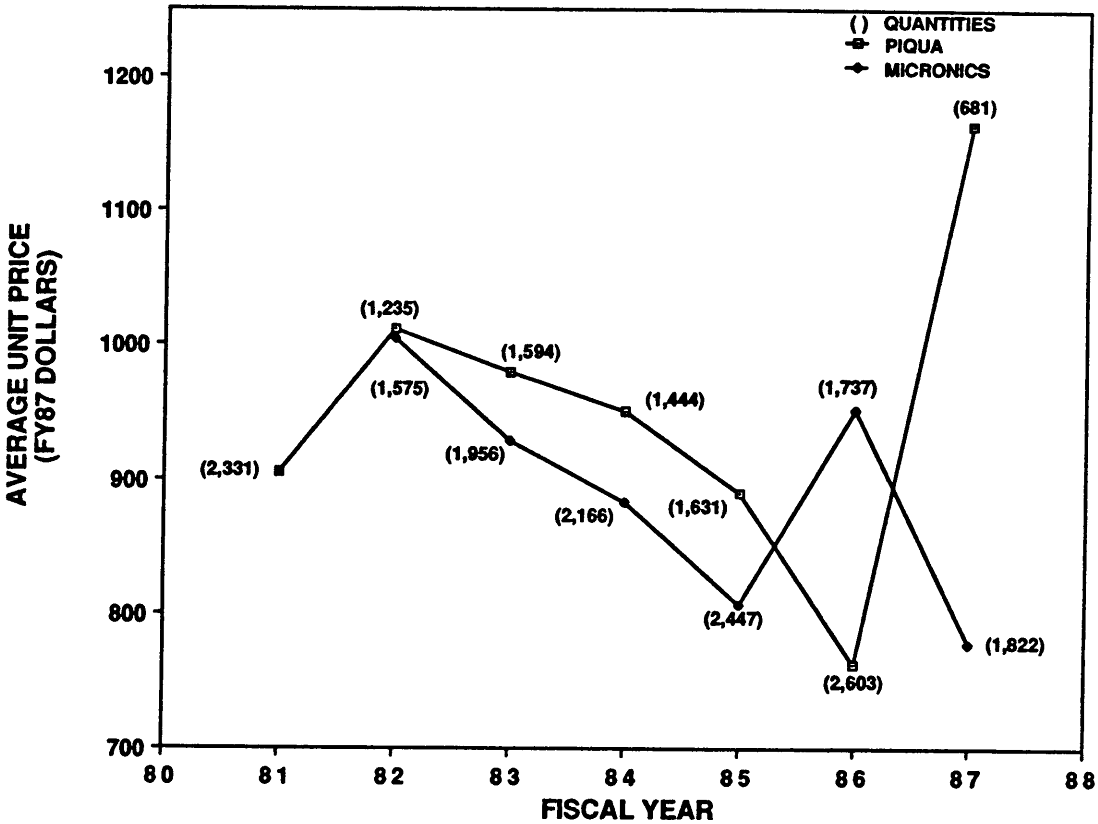

Figure 6.2-1 AIM-9M Safety Arming Device

The parameters that have been developed using the TASC Rate model are presented in Table 6.2-1.

TABLE 6.2-1

AIM-9M SAD PARAMETER ESTIMATES*
(FY87 Dollars)

	FIRST UNIT PRICE	PRICE IMPROVEMENT RATE	PRODUCTION RATE PARAMETER	$\bar{R}^2$
Piqua	$1268	.96 (-5.34)	.80 (-10.45)	.992
Micronics	$1277	.97 (-1.42)	.85 (-1.04)	.661

*T-statistics in parentheses

Tables 6.2-2 and 6.2-3 present the parameter estimates' associated percent error.

TABLE 6.2-2

PIQUA SAD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Predicted	Percent Error
81	2331	905.0	907.0	-0.22
82	1235	1012.0	1039.1	-2.67
83	1594	980.0	936.4	4.45
84	1444	951.0	950.8	0.02
85	1631	890.0	902.5	-1.41
86	2603	762.0	765.6	-0.47
87	681	1164.0	1169.5	-0.47

TABLE 6.2-3

MICRONICS SAD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Predicted	Percent Error
82	1575	1005.0	1029.1	-2.40
83	1956	928.0	908.6	2.09
84	2166	883.0	860.7	2.53
85	2447	806.0	819.6	-1.69
86	1737	952.0	875.6	8.03
87	1822	777.0	858.1	-10.44

Piqua and Micronics bid competitively through the seven lots, with possible gaming behavior in lots six and seven. The price improvement rates of both contractors are relatively flat, which implies that neither contractor is very price responsive to the increase in cumulative quantity over the seven lots. The Piqua production rate parameter is steeper than the Micronics parameter, indicating that Piqua is more price sensitive than Micronics to changes in lot quantity. Test statistics are strong for Piqua, and the parameters signs are negative. Test statistics are fairly weak for Micronics, due primarily to the price spike in lot six. The Micronics parameters also are negative. The SAD first source data were not run on the LCPRC model, as explained in Section 6.1.

Competitive bidding began in lot two. Micronics immediately overcame the Piqua advantage and won the larger portion of the lot. Micronics continued to underbid Piqua, winning lots 3 through 5. Having lost four consecutive buys, Piqua bid low and won lot six. Micronics shows evidence of gaming here. The Micronics price on 1737 units presents a significant price increase above what would be expected for a normal rate adjustment, as compared to Micronics price behavior for FY82 through FY85. In lot seven, Micronics bid low to win 1822 units. Piqua had a very high unit price on 681 units, due primarily to rate adjustment to a smaller quantity.

6.3 WARHEAD

The warhead is produced by the Marquardt Company (first source) and TRW, Inc. The warhead is a carry-over design from an earlier version of the Sidewinder. Competitive bidding began in 1981. There were no directed buys. The Marquardt and TRW pricing data are displayed in Figure 6.3-1.

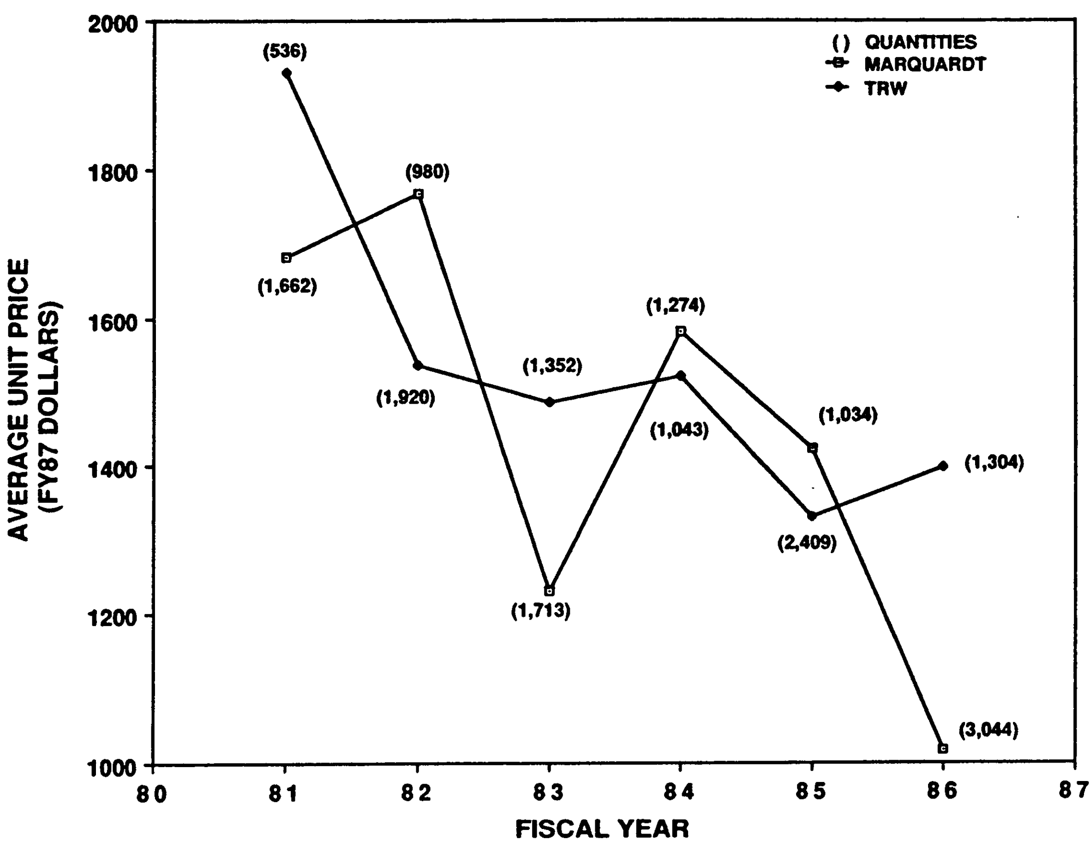

Figure 6.3-1 AIM-9M Warhead

The parameters that have been developed using the TASC Rate model are presented in Table 6.3-1.

TABLE 6.3-1

AIM-9M WARHEAD PARAMETER ESTIMATES*
(FY87 Dollars)

	FIRST UNIT PRICE	PRICE IMPROVEMENT RATE	PRODUCTION RATE PARAMETER	$\bar{R}^2$
Marquardt	$2777	.93 (-3.57)	.79 (-4.13)	.926
TRW	$2484	.95 (-9.18)	.93 (-5.45)	.998

*T-statistics in parentheses

Tables 6.3-2 and 6.3-3 present the parameter estimates' associated percent error.

TABLE 6.3-2

MARQUARDT WARHEAD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	1662	1682.0	1667.3	0.87
82	980	1768.0	1728.2	2.25
83	1713	1231.0	1349.1	-9.59
84	1274	1581.0	1434.7	9.26
85	1034	1424.0	1506.2	-5.77
86	3044	1018.0	1004.4	1.34

TABLE 6.3-3

TRW WARHEAD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	536	1930.0	1990.6	-3.14
82	1920	1536.0	1522.5	0.88
83	1352	1485.0	1488.6	-0.25
84	1043	1522.0	1492.8	1.92
85	2409	1330.0	1340.3	-0.77
86	1304	1399.0	1398.4	0.05

The warhead data indicate that Marquardt and TRW bid competitively through the six lots, with possible gaming by Marquardt in lot four. The price improvement rates of both contractors are relatively flat, which implies that the contractors are not very price sensitive to the increase in cumulative quantity over the six lots. The Marquardt production rate parameter is much steeper than the TRW parameter, which indicates that Marquardt is far more price sensitive than TRW to changes in lot quantity. Test statistics are strong for both regressions and the parameter signs are negative. The warhead first source data were not run on the LCPRC model, as explained in Section 6.1.

Competitive bidding began in lot two. TRW immediately overcame the Marquardt advantage to win the major portion of the lot. Marquardt reacted to the lot two outcome by bidding low to win the major portion of lot three. TRW had a small price decrease on a decreased quantity in lot three.

Lot four is unusual in that the high price bidder won the major portion of the lot. Marquardt's price on 1274 units is $60 per unit higher than the TRW price on 1043 units. This illustrates that the program office did not use price as the sole basis for contract award, as explained in Section 5.1. The TRW lot four price increase is due to rate adjustment. The Marquardt price increase is due primarily to rate adjustment. It is also possible that Marquardt lost money on lot three, and could not afford to bid as low on lot four.

TRW won lot five, with Marquardt showing a price decrease on a decrease in quantity. Having lost lot five, Marquardt bid aggressively to win lot six. TRW had a small rate adjustment price increase for its share of lot six.

6.4 ACTIVE OPTICAL TARGET DETECTOR

The AOTD is produced by the Raytheon Company (first source) and Santa Barbara Research Center (SBRC), a subsidiary of Hughes Aircraft. Competitive bidding began in 1981. There were no directed buys. The Raytheon and SBRC pricing data are displayed in Figure 6.4-1.

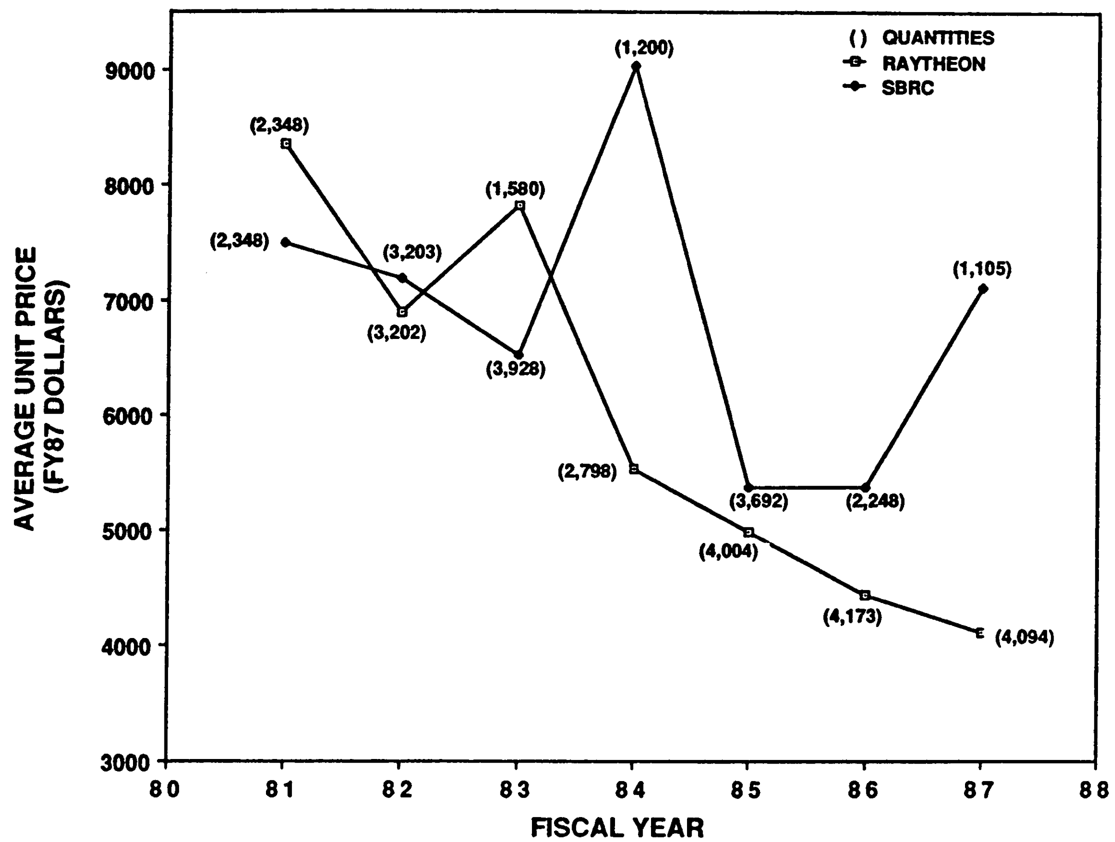

Figure 6.4-1 AIM-9M Active Optical Target Detector

The parameters that have been developed using the TASC Rate model are presented in Table 6.4-1.

TABLE 6.4-1

AIM-9M AOTD PARAMETER ESTIMATES*
(FY87 Dollars)

	FIRST UNIT PRICE	PRICE IMPROVEMENT RATE	PRODUCTION RATE PARAMETER	$\overline{R}^2$	SUM OF SQUARED ERRORS
Raytheon	$19,376	.90 (-3.94)	.77 (-2.40)	.785	8.98
SBRC	$13,538	.94 (-1.82)	.90 (-1.06)	.889	19.50

*T-statistics in parentheses

Tables 6.4-2 and 6.4-3 present the parameter estimates' associated percent error.

TABLE 6.4-2

RAYTHEON AOTD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	2348	8346.0	8814.6	-5.61
82	3202	6890.0	6204.3	9.95
83	1580	7820.0	7492.8	4.18
84	2798	5538.0	5788.8	-4.53
85	4004	4994.0	4813.8	3.61
86	4173	4442.0	4533.4	-2.06
87	4094	4109.0	4410.5	-7.34

TABLE 6.4-3

SBRC AOTD PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	2348	7492.0	8067.8	-7.69
82	3203	7193.0	6695.5	6.95
83	3928	6531.0	6108.4	6.47
84	1200	9025.0	7183.5	20.40
85	3692	5380.0	5889.5	-9.47
86	2248	5375.0	6253.5	-16.34
87	1105	7099.0	6940.3	2.24

The AOTD data indicate that both Raytheon and SBRC bid competitively over the seven lots, with possible gaming by SBRC in lot four. Both contractors have fairly flat price improvement curves, implying that they are not very price sensitive to the increase in cumulative quantity over the seven lots. The Raytheon production rate parameter is much steeper than the SBRC parameter, which indicates that Raytheon is far more price sensitive than SBRC to changes in lot quantity. Test statistics are fairly strong for Raytheon, and the parameter signs are negative. The SBRC $\overline{R}^2$ is good and the parameter signs are negative. The t-statistics are weak, however, due primarily to the price spike in lot four.

Competitive bidding began in lot one, though lots one and two appear to be directed buys. Both contractors were awarded the same quantity, although unit prices differed by $854 in the first lot and $303 in the second.

SBRC won lot three, with Raytheon showing a price increase due to rate adjustment. Having lost lot three, Raytheon bid aggressively and won lot four. SBRC shows evidence of gaming here. The SBRC lot four price on 1200 units presents a significant price increase above what would be expected for a normal rate adjustment as compared to SBRC's price behavior for FY85 through FY87.

Raytheon won lots five through seven, with prices decreasing over stable quantities. SBRC flattened prices over decreasing quantities in lots five and six, and had a rate adjustment price increase in lot seven.

The Raytheon data also were run on the LCPRC model, as explained in Section 6.1. The parameters that have been developed are:

- First Unit Price = $13,084 (FY87 Dollars)
- Price Improvement Rate (FY81-FY83) = .94
- Competitive Price Improvement Rate (FY84-FY87) = .83
- Production Rate Parameter = .88
- Percent Shift = 11.77
- Percent Rotation = 12.62.

Table 6.4-4 presents the parameter estimates' associated percent error.

TABLE 6.4-4

RAYTHEON LCPRC PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Predicted	Percent Error
81	2348	8346.0	8352.1	-0.07
82	3202	6890.0	6949.3	-0.86
83	1580	7820.0	7598.7	2.83
84	2798	5538.0	5691.5	-2.77
85	4004	4994.0	4853.2	2.82
86	4173	4442.0	4435.4	0.15
87	4094	4109.0	4175.0	-1.61

The sum of squared errors for the regression was 10.03.

Raytheon reacted to the price pressure exerted by SBRC with a drop in unit prices as evidenced by the 11.77 percent shift in its price improvement curve. Continuing price reductions are evidenced by the 12.62 percent rotation of the curve. Raytheon's competitive price improvement rate of .83 is steeper than its pre-shift rate of .94. The steeper price improvement rate allows Raytheon to remain competitive with SBRC through the remainder of the competitive phase. The production rate parameter of .88 indicates that Raytheon is somewhat price sensitive to changes in lot quantity.

6.5 ROCKET MOTOR

The rocket motor is produced by Thiokol (first source) and Hercules-McGregor. The 1981 lot was a directed buy for both companies. Competitive bidding began in 1982. The Thiokol and Hercules pricing data are displayed in Figure 6.5-1.

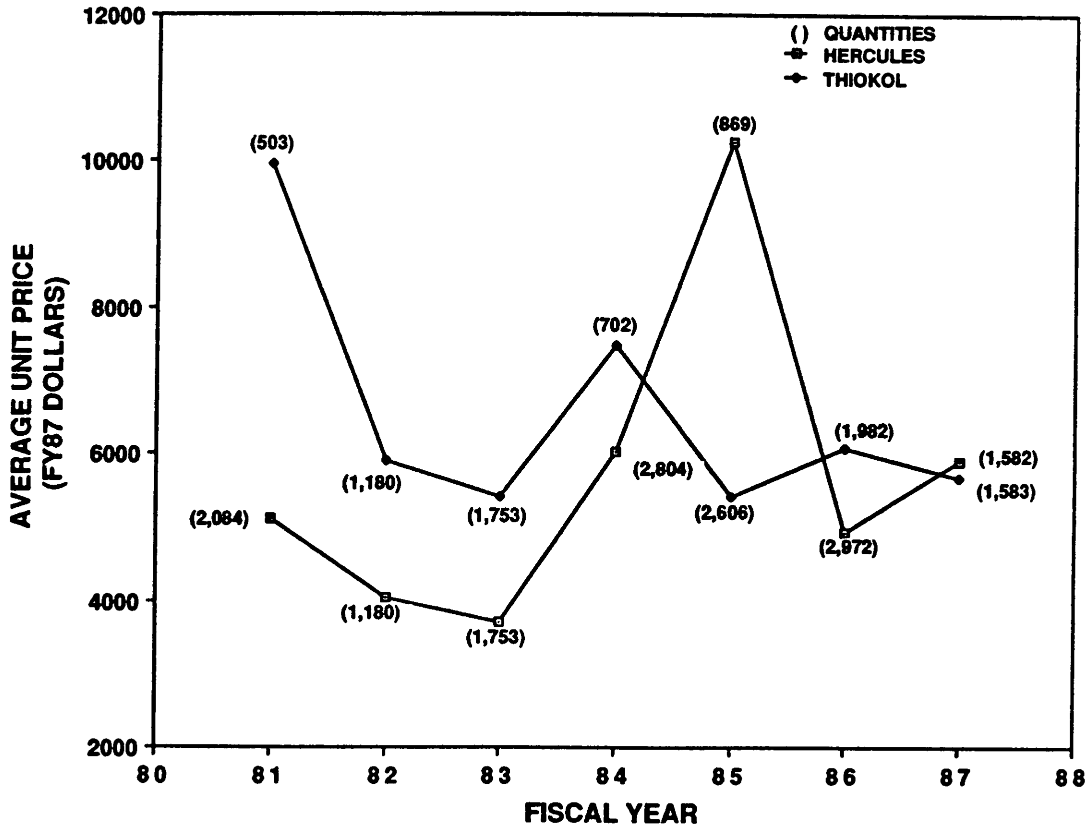

Figure 6.5-1 AIM-9M Rocket Motor

The parameters that have been developed using the TASC Rate model are presented in Table 6.5-1.

TABLE 6.5-1

AIM-9M ROCKET MOTOR PARAMETER ESTIMATES*
(FY87 Dollars)

	FIRST UNIT PRICE	PRICE IMPROVEMENT RATE	PRODUCTION RATE PARAMETER	$\bar{R}^2$
Thiokol	$5093	1.01 (.08)	.84 (-2.19)	.935
Hercules	$2558	1.06 (.62)	.88 (-.60)	.575

*T-statistics in parentheses

Tables 6.5-2 and 6.5-3 present the parameter estimates' associated percent error.

TABLE 6.5-2

THIOKOL ROCKET MOTOR PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Average Unit Price Predicted	Percent Error
81	503	9965.0	7947.1	20.25
82	1180	5893.0	6435.1	-9.20
83	1753	5431.0	5836.9	-7.47
84	702	7482.0	7393.8	1.18
85	2606	5416.0	5290.6	2.32
86	1982	6081.0	5684.2	6.52
87	1583	5668.0	6027.0	-6.33

TABLE 6.5-3

HERCULES ROCKET MOTOR PARAMETER ESTIMATES PERCENT ERROR
(FY87 Dollars)

Fiscal Year	Quantity	Average Unit Price Actual	Predicted	Percent Error
81	2084	5100.0	4638.9	9.04
82	1180	4048.0	5647.2	-39.51
83	1753	3709.0	5451.3	-46.97
84	2804	6034.0	5193.7	13.93
85	869	10273.0	6526.2	36.47
86	2972	4936.0	5334.4	-8.07
87	1582	5905.0	6006.6	-1.72

The rocket motor data show competitive behavior in lots one through three, and noncompetitive and gaming tendencies in lots four through seven. The price improvement rates of both contractors are greater than one. This is interpreted as prices increasing as cumulative quantity increases, and is indicative of noncompetitive behavior. The Thiokol production rate parameter is steeper than the Hercules parameter, indicating that Thiokol has greater price sensitivity to lot quantity changes than Hercules. The test statistics are generally poor for both regressions. This is due to the price increases of both contractors in lot four, and the flattening of prices in lots five through seven. The price improvement parameter signs for both regressions are positive, because the price improvement rates are greater than one. The production rate parameter signs are negative for both regressions.

Hercules and Thiokol performed competitively in the first three lots, prices declining with each buy. In lot four, prices increased more than $2000 per unit for each contractor. The price increase was due primarily to a modification to the rocket motor testing program, which required the contractors to perform radiographic inspection of the motor. This was due to government concerns about the motor's propellant.

Having lost lot four, Thiokol bid low and won the major portion of lot five. Hercules shows evidence of gaming here. The Hercules price on 869 units presents a significant price increase above what would be expected for a normal rate adjustment as compared to Hercules price behavior for FY81 through FY83.

Hercules bid low and won lot six. Thiokol exhibited a small rate adjustment price increase on the lot. By lot seven, it appears that Thiokol and Hercules have deduced each other's bid pricing strategies. The bids were so close they warranted only a one unit difference in the quantity split.

After the price increase in lot four, neither contractor showed the dramatic price decreases of lots one through three. This flattening of prices is indicative of noncompetitive behavior.

CHAPTER 7

CONCLUSION

The purpose of this study was to analyze the effects of competition on defense contractor pricing behavior. This was accomplished through the examination of dual source subsystem data from the AIM-9M Sidewinder missile program.

Key findings of this study include the following:

- Introduction of a second source led to increased price reductions by the first source.
- The first source exhibited a greater price sensitivity to lot quantity changes than the second source.
- The second source was immediately price competitive with the first source.
- Each subsystem showed evidence of gaming. Only one subsystem showed evidence of noncompetitive behavior.

For all five subsystems the first source exhibited a steeper price improvement rate than the second source, as measured by the Rate model. In addition, the LCPRC model calculated first source competitive price improvement rates that were much steeper than the pre-competition rates. These steeper price improvement rates indicate that first source price reductions increased with the introduction of a second source.

The first source exhibited steeper production rate curves than the second source for all five subsystems. Thus, there was a greater first source price sensitivity to lot quantity changes. This can further be interpreted as gaming behavior by the first source, an attempt to "punish" the government (through higher prices) for bringing on a second source and taking production quantity away from the first source.

For four of the subsystems (except the SAD), the second source had a lower first unit price than the first source. For the SAD, the second source first unit price was estimated at $9 above that of the first source. This indicates that the second source was immediately price competitive with the first source. As shown in Figure 3.1-2, this is the type of pricing behavior exhibited on prior electronic subsystems.

Contractor gaming was seen on each subsystem. The SAD, warhead, AOTD, and rocket motor each showed evidence of gaming on specific lots. Evidence of first source production rate gaming was seen on all of the subsystems.

Noncompetitive behavior was evident only for the rocket motor.

This study supports previous findings that competition positively affects defense contractor pricing. It also raises concerns about contractor gaming in the competitive procurement process. This highlights the need for additional research on the development of competitive solicitation techniques that avoid gaming and minimize the potential for tacit collusion.

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